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(54) Title: **MULTI-CHANNEL DOWNMIXING DEVICE**

(57) Abstract: A method and system are provided for generating one or more mix coefficients for downmixing a multichannel input signal having a plurality of input channels, to an output signal having a plurality of output channels. Mix coefficients may be generated responsive to a comparison of energy between the downmixed (output) signal and the input signal to the downmixer, such that energy and intended direction of the input signal are substantially preserved in the output signal. Further, or in the alternative, the mix coefficient generation may preserve an intended direction of an input signal, for example, received at a surround input channel, in at least one output channel of the output signal. The mix coefficient values may be generated in a test downmixer environment. Additionally, one or more mix coefficients may be generated by retrieving predetermined mix coefficient values. Additionally, or in the alternative, one or more mix coefficients may be generated responsive to an input energy of a plurality of the input channels.

MULTICHANNEL DOWNMIXING DEVICE

INVENTOR:

David H. Griesinger

BACKGROUND OF THE INVENTION

1. Technical Field.

[01] This application claims priority to U.S. Provisional Application No. 60/377,661, attorney docket number 11336/137, entitled "A Multichannel To Two Channel Mixing Device And Method," by David H. Griesinger, filed May 3, 2002, and is hereby incorporated by reference.

2. Related Art.

[02] The invention relates to a mixing device, and more specifically, to a downmixer capable of mixing a multichannel signal including a plurality of channels to an output signal including a plurality of channels, while preserving the intended direction and signal energy of the multichannel signal.

[03] Often, audio recordings, or movie soundtracks (film mixes), are created with more than two audio channels, to give a listener a more realistic feeling that the audio recording is live. For example, film mixes may be created as 3 channel recordings, providing left front (LF), right front (RF) and center (C) channels. Film mixes may instead be created as 5 channel recordings, including the LF, RF and C channels, along with rear left (RL) and rear right (RR) channels, or in some circumstances, as 5.1 channel recordings including the channels of the 5 channel recording plus a low frequency (LFE) channel.

[04] However, the listener of the audio recording or film mix may have an audio system that supports less channels than the number of channels in which the audio recording or film mix has been created. Typically, this occurs when the listener's audio system supports only 2 channel (i.e., stereo) playback. In this circumstance, such recordings are

provided to a listener as a 2 channel recording by utilizing a combiner (downmixer) to combine, or downmix, the multichannel signal to 2 channels. The downmixing may occur at an encoder, for example, where a 2 channel recording is provided on the media (i.e., CD, DVD, etc.). The downmixing may occur at a decoder of the listener's audio system where
5 the decoder downmixes the multichannel signal to the 2 channel mix.

[05] When downmixing a multichannel signal to 2 channels, downmixers typically employ fixed mix coefficients. A common downmixer used for 5 channel film recordings mixes the two rear channels together before mixing them in antiphase to the output channels. This may cause any signal in the rear channels to reproduce from the rear in standard film
10 decoders. However, information about whether the sound was from the left rear or the right rear is typically lost.

[06] A common downmixer for classical music, for example utilizing a European Standard for 5 channel downmixing, mixes the two rear channels directly into the output channels, without any inversion of phase. This may preserve the left/right directionality of
15 the rear channels, but does not preserve an indication that the signals were intended to be heard behind the listener. The resulting mix causes the downmixed signal to appear as if it were in front of the listener, both in two channel playback, and when played through a standard film decoder.

[07] Some downmixers may slightly vary mix ratios as an attempt to preserve
20 signal energy, for example, where surround input signals are anticorrelated with respect to one another. However, signal energy and apparent direction of the multichannel signal is not substantially preserved, for example, where the input signal pans between input channels.

[08] Further, both the standard film downmixer, and the European Standard downmixer attenuate the rear channels by 3dB before mixing them into the output channels.
25 This attenuation may cause the loudness of a sound effect applied to one of the rear channels to be lower than the original five channel mix. In this case the energy in the rear inputs is not preserved in the output channels.

[09] Yet another problem with the above discussed encoders/decoders is in the handling of sound events (i.e., a short burst of sound with a well defined beginning and that
30 may or may not have a well defined end, such as notes from an instrument, or syllables in speech) when downmixing the input signal. The downmixing algorithms employed cause the sound event to be reduced in emphasis in the downmixed signal, especially in the presence of

reverberation. The downmixers discussed above cause the sound events to be downmixed in the front channels. However, when these sound events are downmixed into the front channels, they may become less audible or even inaudible.

[10] Further, downmixers that mix three front channels into two output channels suffer from a directional localization problem, where sounds that are mixed in a three channel recording so they are perceived as coming half-way between the left (or right) front channel and the center channel, are perceived as coming from a different spot when the three channel signal is downmixed to two channels and reproduced through two loudspeakers. In practice, the sound image in the two channel downmix is almost at the left loudspeaker (or right), instead of exactly half-way between the center and the left.

[11] Therefore, a need exists for a downmixer that preserves the intended direction and the signal energy of a multichannel mix. Additionally, a need exists for a downmixer that properly mixes an input signal in the presence of reverberation and that emphasizes sound events within the input signal during the downmixing process.

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SUMMARY

[12] A downmixer system is provided for generating mix coefficients for downmixing a multichannel input signal having a plurality of input channels, to an output signal having a plurality of output channels. Mix coefficients may be generated responsive to a comparison of energy between the downmixed (output) signal and the input signal to the downmixer, such that energy and intended direction of the input signal is substantially preserved in the output signal. The number of input channels of the input signal may be greater than, or equal to, the number of output channels in the output signal. Further, or in the alternative, the mix coefficient generation may preserve intended direction of an input signal, for example, received at a surround input channel, in at least one output channel of the output signal. In this circumstance, the preserved intended direction may be utilized at an upmixer capable of decoding surround channel information, to place the surround channel information in the surround channel(s) of the upmix.

[13] The mix coefficients may be generated in a test downmixer environment, where the test downmixer environment may be utilized to generate the mix coefficients responsive to input and output signal energy determined using limited-bandwidth (i.e.,

filtered) input signals received at the test downmixer. The mix coefficients determined using the test downmixer may then be utilized in a full-bandwidth downmixer.

[14] Mix coefficient values may be generated by retrieving predetermined mix coefficient values. The predetermined mix coefficient values may be stored in a tabular format at a storage device of the downmixer, for example, as one-dimensional or two-dimensional tables. The tables may be indexed by a ratio of output energy to input energy. When a substantially similar output to input ratio is encountered while downmixing an input signal, it may be possible to retrieve one or more mix coefficients from a mix coefficient table to be used in downmixing the input signal.

[15] Mix coefficients may be generated responsive to an input energy of a plurality of the input channels. An energy ratio between at least one of the input channels and at least another of the input channels may be determined, where the mix coefficient generation is responsive to the energy ratio. The mix coefficient generation may include increasing one or more mix coefficient values, or decreasing one or more mix coefficient values. Further, a beginning of a sound event may be detected, where the mix coefficient generation may be responsive to the input energy and the beginning of the sound event detection.

[16] Other systems, methods, features and advantages of the invention will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[17] The invention can be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like referenced numerals designate corresponding parts throughout the different views.

[18] Figure 1 is a functional block diagram of a downmixer device for downmixing a three channel input signal to a two channel output signal.

[19] Figure 2 is a flowchart illustrating operation of the downmixer device of Figure 1.

[20] Figure 3 is a flowchart illustrating generation of the mix coefficients of the downmixer of Figure 1 and the downmixer of Figure 9.

5 [21] Figure 4 is a flowchart illustrating the determining channel energy of Figure 3 that may be used in downmixing a three channel input signal to a two channel output signal.

[22] Figure 5 is a flowchart illustrating the determining of a feedback constant of Figure 3 that may be used in downmixing a three channel input signal to a two channel output signal.

10 [23] Figure 6 is a flowchart illustrating the generating of channel mix coefficients of Figure 3 that may be used in downmixing a three channel input signal to a two channel output signal.

[24] Figure 7 is a graph of mix coefficients generated in accordance with the flow charts of Figures 4-6 for a single input signal panned from the center to left channel.

15 [25] Figure 8 is a graph of mix coefficients as a function of panning angle, derived experimentally to compensate for the subtle error in localization when a three channel signal is downmixed and reproduced through two channels.

[26] Figure 9 is a functional block diagram of a downmixer device for downmixing a 5.1 channel input signal to a two channel output signal.

20 [27] Figure 10 is a flowchart illustrating operation of the downmixer device of Figure 9.

[28] Figure 11 is a flowchart illustrating determining I/P and O/P channel energy for generation of Figure 3 for the downmixer of Figure 9.

25 [29] Figure 12 is a flowchart illustrating the generating of at least one feedback constant of Figure 3 for the downmixer of Figure 9.

[30] Figure 13 is a flowchart illustrating the generating one or more mix coefficients of Figure 3 for the downmixer of Figure 9.

[31] Figure 14 is a flowchart illustrating the adjusting of mix coefficients generated for the downmixer of Figure 9.

30 [32] Figure 15 is a flowchart illustrating the determining channel energy of Figure 14.

[33] Figures 16 – 17 are flowcharts illustrating the adjusting of one or more mix coefficients of Figure 14.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[34] A downmixer system is provided for generating mix coefficients for
5 downmixing a multi-channel input signal having a plurality of input channels to an output signal having a plurality of output channels. An input energy level may be determined for at least a plurality of the input channels, and mix coefficients may be generated responsive to the determining at least one of the input and output energy levels such that the signal energy and the intended direction of the input signal are substantially preserved. An output energy
10 level may be determined for at least one of the output channels, where mix coefficients may be generated responsive to the input and output signal energy such that the signal energy and the intended direction of the input signal are substantially preserved in the output signal.

[35] The number of output channels in the output signal may be less than the number of input channels of the input signal, for example, when a three channel input signal
15 is downmixed to a two output channel output signal. The number of input channels of the input signal may be equal to the number of output channels of the output signal, for example, where the downmixer is utilized to downmix surround channel information.

[36] The downmixer may provide a listener of the output signal with a substantially accurate rendition of the apparent direction and relative loudness of the input signal. When
20 downmixing an input signal including both front channel and surround channel information, the downmixer may be capable of downmixing the front channel and surround channel information independently, to substantially preserve energy and intended direction of the input signal at the output signal. The downmixed surround and downmixed front channel information may be combined (i.e., added together) to produce a two channel mix of the input
25 signal.

[37] The downmixer may be capable of altering an energy ratio between front input channels and surround input channels of the input signal during downmixing of the input multichannel signal to the output signal. The energy ratio alterations may be utilized to provide a substantially accurate rendition of reverberation present in the multichannel input
30 signal to the output signal. The energy ratio alterations for downmixing may be

accomplished through mix coefficient adjustments. Additionally, mix coefficients may be adjusted to emphasize sound events (i.e., notes from an instrument, syllables (phones) of speech, etc.). Sound events may occur in one or more of the input channels, for example, the left and right surround channels, to provide a substantially accurate rendition of the sound events at the output signal of the downmixer.

[38] Downmixers for downmixing input signals with 3 input and 5.1 input channels to an output signal having 2 output channels will be discussed below. However, it will be apparent that the teachings herein may be applied to input signals having a different number of input channels, and that may be downmixed to an output signal with more than two output channels.

[39] Figure 1 is a functional block diagram of a downmixing device capable of downmixing a multi-channel input signal including at least 3 input channels to an output signal including a number of output channels less than the number of input channels, here 2 output channels. As shown in Figure 1, a downmixer 100 includes a full-bandwidth downmixer generally indicated at 102, for downmixing the multi-channel input signal to the output signal responsive to generated left and right channel mix coefficients m_l and m_r , such that signal energy and an intended direction of the input signal are substantially preserved in the output signal. The full-bandwidth downmixer 102 is capable of downmixing over a broad range of frequencies, for example, over the 20 – 20,000 frequency range. Other frequency ranges are possible. The downmixer 100 may further include a test downmixer 104, and a controller 106, where the test downmixer 104 and controller 106 may be utilized for generating test mix coefficient values, that may be used to update the left and right mix coefficients m_l and m_r of the full-bandwidth downmixer 102, to allow substantial preservation of the signal energy and intended direction of an input signal at the output signal, as described below. The test downmixer may operate over a limited frequency range, for example 700 – 4000 Hz frequency range. Other frequency ranges are possible. The limited frequency range of operation of the test downmixer may be advantageous as allowing the mix coefficients of the full-bandwidth downmixer 102 to be generated using a range of frequencies over which human listeners may be particularly sensitive. Generating the mix coefficients in this fashion may allow for mix coefficient generation that more accurately reflects loudness of the input signal at the output signal, as perceived by human listeners.

[40] As energy and intended direction are substantially preserved at the test downmixer 104 using the test mix coefficients, the test mix coefficient values, if used in the full-bandwidth downmixer, will allow the energy and intended direction of the input signal at the full-bandwidth downmixer to be substantially preserved in the output signal. Upon
5 generation of the mix coefficients by the test downmixer 104 and controller 106, the generated values may be utilized to update the mix coefficients of the full-bandwidth downmixer 102.

[41] As shown in Figure 1, the full-bandwidth downmixer 102 is capable of downmixing an input signal having 3 channels, for example, left (LI), center (CI) and right
10 (RI) input channels to be downmixed to an output signal having 2 channels, for example, left output (LO) and right output (RO) channels.

[42] The full-bandwidth downmixer 102 includes a first mixer 108 and a second mixer 110, the first and second mixers specifying mix coefficients including a left channel mix coefficient m_l and a right channel mix coefficient m_r respectively, for mixing the CI
15 channel with the LI and RI channels. The CI channel may be mixed with the LI and RI channels to generate respective L' and R' channels. The first mixer 108 is coupled with a first phase shifter 112 for providing a desired phase shift to the L' channel, for generating the LO channel of the output signal. Similarly, the second mixer 110 is coupled with a second phase shifter 114 for applying a desired phase shift to the R' channel, for generating the RO
20 channel of the output signal. The phase shifters 112 and 114 may be capable of providing a pure phase shift to the L' and R' channel information such that the energy and amplitude of the L' and R' are not affected at any frequency.

[43] The test downmixer 104 may include a first test mixer 116 and a second test mixer 118. The first test mixer 116 may be capable of receiving at least one of a limited-
25 bandwidth (i.e., filtered) LI and CI channel information as LI_{Lim} and CI_{Lim} , respectively, and mixing the LI_{Lim} and CI_{Lim} channel information using a test left channel mix coefficient m_l' to form a limited-bandwidth test mixer left output channel LO_{Lim} . Similarly, the second test mixer 118 may be capable of receiving at least one of a limited-bandwidth RI channel information RI_{Lim} and the CI_{Lim} channel information, and mixing the RI_{Lim} and CI_{Lim} channel
30 information using a test right channel mix coefficient m_r' to form a limited-bandwidth RO output channel RO_{Lim} of the test mixer 104.

[44] The controller 106 is coupled with the first mixer 108, the second mixer 110, the first test mixer 116 and the second test mixer 118. The controller 106 is capable of receiving one or more of the LI, CI and RI channel information of the input signal, and determining limited-bandwidth (i.e., filtered) channel information, for example, LI_{Lim} , CI_{Lim} , and RI_{Lim} for use in the test downmixer 104. The controller 106 is additionally capable of receiving output channel information, for example the output channel information LO and RO from the full-bandwidth downmixer 102, and/or the limited-bandwidth output channel information LO_{Lim} and RO_{Lim} from the test downmixer 104, and generating values for one or more mix coefficients, for example, the mix coefficients ml and mr of the full-bandwidth downmixer 102, as described below using the test downmixer 104. The controller 106 may further be coupled with a storage device 120, providing one or more memory devices that may be utilized by the controller 106, for example, as a working memory and/or program memory during operation of the downmixer.

[45] Figure 2 is a flow chart illustrating operation of the downmixer 100 in downmixing a multi-channel (i.e., > 2 channel) input signal, here having three channels, to an output signal having a number of channels less than input signal, here two channels. As shown in Figure 2, input channel information is received 200 at the full-bandwidth downmixer 102, for example as LI, CI, and RI channel information.

[46] The controller 106 is capable of generating 202 at least one of the mix coefficients ml and mr used by the first and second mixers 108 and 110 to mix the LI, CI and RI channel information, for example, using the test downmixer 104, as will be discussed below. The full-bandwidth downmixer 102 may mix 204 the LI and CI channels at the first mixer 108 to form the L' channel, as

$$L' = LI + ml * C. \quad (\text{eqn. 1})$$

[47] The first phase shifter 112 may then provide 206 a desired phase shift to the L' channel information, where the resulting channel information is provided 212 as the LO channel of the output signal.

[48] Similarly, the second mixer 110 may mix 208 the RI and CI channels to form the R' channel, as

$$R' = RI + mr * C. \quad (\text{eqn. 2})$$

[49] The second phase shifter 114 may then provide 210 any desired phase shift to the R' channel information, where the resulting channel information is provided 212 as the RO channel of the output signal.

[50] Although the generating 202 is shown as occurring at a particular location in the flow chart of Figure 2, it will be apparent that the generating of mix coefficients may be accomplished at any time during the operation of the full-bandwidth downmixer 102 and/or may be accomplished at multiple intervals during operation of the full-bandwidth downmixer 102.

[51] The mix coefficients m_l and m_r may be generated 202 at the same time or at separate times during operation of the full-bandwidth downmixer 102. Additionally, in some circumstances, it may be desirable to generate only a single mix coefficient, for example, m_l or m_r , to be utilized by the full-bandwidth downmixer 102. Further, or in the alternative, the generating 202 may be accomplished periodically during mixing of the input signal, for example, at some time interval (i.e., every 1.5 ms or 10 ms), or after processing a particular amount of input channel information (i.e., 64 samples or 640 samples of input channel information). Upon generating one or both of the mix coefficients m_l and m_r , the controller 106 may update the respective first and/or second mixer 108 and 110 with an updated value for one or both of the updated mix coefficients. Such updating of mix coefficient values may occur any time during downmixing of an input signal to the output signal.

[52] Mix coefficient generation will be described generally with respect to the flow chart of Figure 3. The flow charts and graphs of Figures 3-8 and 11-13 will be discussed in the context of Figure 3, to describe mix coefficient generation for various circumstances.

[53] Figure 3 is a flowchart illustrating the generating 202 of the mix coefficients, for example, the left and right channel mix coefficients m_l and m_r . The mix coefficient generation may occur, for example, at the test mixer 104 and controller 106. As shown in Figure 3, at least one of an input and an output channel energy may be determined 300, for example, by the controller 106, using the test downmixer 104. The controller 106 may then determine 302 one or more feedback constants, for example, to smooth/stabilize mix coefficient value generation, especially in the presence of rapidly varying input channel information. The controller may then generate 304 mix coefficient(s), for example, the test mix coefficients m_l' and m_r' responsive to the channel energy and/or feedback constant(s).

The mix coefficients of the full-bandwidth downmixer 102 may be updated with the values of the test mix coefficients.

[54] As is described below, the controller 106 typically generates the mix coefficient values utilizing limited-bandwidth input signal information, for example, by filtering the LI, CI and/or RI channel information to accentuate audible frequencies, for example, in the 700-4000 Hz frequency range. The filtering may accentuate other frequency ranges. Filtering the input channel information may allow the generated mix coefficients to reflect more accurately the loudness of the sound as perceived by human listeners. Although the full-bandwidth downmixer 102 is typically a broad band downmixer capable of downmixing input signals over a broad range of frequencies, for example 20 Hz - 20 KHz, human hearing may be particularly sensitive to the energy content in the middle frequencies, for example the 700-4000 Hz frequency range, and determining the mix coefficients responsive to the middle frequency range is advantageous as allowing loudness of the input signal to be preserved in frequencies to which human listeners are most sensitive. Alternatively, or in addition, the controller 100 may generate mix coefficient values using full-bandwidth input channel information (i.e., non-filtered input channel information).

[55] The generating of one or more mix coefficients will be discussed below for various situations. For example, Figures 4-6 are flowcharts illustrating operation of the controller 106 utilizing the test downmixer 104 for generating mix coefficients that may be used in downmixing a three channel input signal to a two channel output signal. Figure 7 is a graph illustrating mix coefficients generated by the downmixer 100 in accordance with the flowcharts of Figures 4-6, with a particular input signal, such that energy and intended direction of the input signal is substantially preserved at the output signal. Figure 8 is a graph illustrating ideal mix coefficients determined experimentally for the particular input signal, such that energy and intended direction of the input signal is substantially preserved at the output signal. An input signal scenario used in generating the graphs of Figures 7 and 8, may be utilized in generating predetermined mix coefficient values as described below. Other input signal scenarios may be used. Figures 11-13 illustrate mix coefficient generation for a downmixer capable of downmixing 5.1 input channels to two output channels.

[56] Figures 4-6 are flow charts illustrating the mix coefficient generation of Figure 3 that may be utilized in downmixing a three channel input signal to a two channel output signal.

[57] Figure 4 is a flow chart illustrating operation of the controller 106 and the test downmixer 104 in determining 300 at least one of an input and output channel energy. As shown in Figure 4, input channel information is received 400 at the controller 106, including LI, CI and RI channel information. The input channel information 400 that is received may include one or more digital signal samples of audio information received as the input signal representing at least one of the LI, CI and RI channel information.

[58] The input channel information may be filtered 402 by the controller 106 to form limited-bandwidth input channel information LI_{Lim} , CI_{Lim} and RI_{Lim} . For example, the input channel information may be filtered to emphasize substantially audible frequencies of the input signals, such as in the 700 to 4,000 Hz frequency range. Limited-bandwidth input channel energy may then be determined 404 by the controller 106 for LI and RI channels, respectively, as

$$ELI_{Lim} = LI_{Lim}^2 + CI_{Lim}^2, \text{ and} \quad (\text{eqn. 3})$$

$$ERI_{Lim} = RI_{Lim}^2 + CI_{Lim}^2. \quad (\text{eqn. 4})$$

[59] A limited bandwidth LO and RO channel information LO_{Lim} and RO_{Lim} may be determined 406 at the test downmixer 104, as

$$LO_{Lim} = LI_{Lim} + ml' * CI_{Lim}, \text{ and} \quad (\text{eqn. 5})$$

$$RO_{Lim} = RI_{Lim} + mr' * CI_{Lim}. \quad (\text{eqn. 6})$$

[60] Limited-bandwidth output channel energy may determined 408 by the controller 106 for the LO and RO channels, respectively, as

$$ELO_{Lim} = LO_{Lim}^2, \text{ and} \quad (\text{eqn. 7})$$

$$ERO_{Lim} = RO_{Lim}^2. \quad (\text{eqn. 8})$$

The limited-bandwidth input and output channel energy determined at 404 and 408 are typically averaged by the controller 106 over a plurality of samples of the input channel information received at the controller 106. The plurality of samples comprise a first time period, that may include, for example, 64 samples of the received 400 input channel information.

[61] The limited-bandwidth input and output channel energy is determined as total limited-bandwidth energy for the LI_{Lim} , LO_{Lim} , RI_{Lim} , and RO_{Lim} channels that may be averaged 410 as ELI_{Sum} , ELO_{Sum} , ERI_{Sum} , ERO_{Sum} channel energy, respectively, where

$$ELI_{Sum} = ELI_{Sum} + ELI_{Lim} \quad (\text{eqn. 9})$$

$$ERI_{Sum} = ERI_{Sum} + ERI_{Lim} \quad (\text{eqn. 10})$$

$$ELO_{Sum} = ELO_{Sum} + ELO_{Lim}, \text{ and} \quad (\text{eqn. 11})$$

$$ERO_{Sum} = ERO_{Sum} + ERO_{Lim}. \quad (\text{eqn. 12})$$

[62] Next, it may be determined 412 whether the averaging is complete. Where it is determined 412 that the averaging is not complete, flow returns to the receiving 400 input channel information as discussed above. However, where it is determined 412 that the first time period is complete, total limited-bandwidth input and output channel energy is determined 414 as total limited-bandwidth left and right channel input and output energy $EINL_{Lim}$, $EINR_{Lim}$, $EOUTL_{Lim}$, and $EOUTR_{Lim}$ respectively, where

$$EINL_{Lim} = ELI_{Sum} + ECI_{Sum} \quad (\text{eqn. 13})$$

$$EINR_{Lim} = ERI_{Sum} + ECI_{Sum} \quad (\text{eqn. 14})$$

$$EOUTL_{Lim} = ELO_{Sum}, \text{ and} \quad (\text{eqn. 15})$$

$$EOUTR_{Lim} = ERO_{Sum}. \quad (\text{eqn. 16})$$

[63] Upon determining at least one of an input and an output channel energy at 300, a feedback constant(s) may be determined 302 in accordance with the flowchart of

Figure 5.

[64] Figure 5 is a flowchart illustrating operation of the controller 106 in determining at least one feedback constant for generating mix coefficients to downmix a three channel input signal to two output channels. At 500 it is determined whether a total LO channel energy, $EOUTL_{Lim}$, is greater than a total limited-bandwidth LI channel energy, $EINL_{Lim}$. Where it is determined 500 that the total limited-bandwidth LO energy is not greater than the total limited-bandwidth LI energy, a left-channel feedback constant fbl may be generated 502 by the controller 106 as

$$fbl = 0.98 * fbl. \quad (\text{eqn. 17})$$

The left-channel feedback constant fbl may be initialized to a value of, for example, 1. Other initial values for the feedback constant may be utilized, for example, between 0 and 1.

However, where it is determined 500 that the total limited-bandwidth LO channel energy is greater than the total limited-bandwidth LI channel energy, a left-channel feedback constant is generated 504 by the controller 106 as

$$fbl = 0.98 fbl + gfb ((EOUTL_{Lim} / EINL_{Lim}) - 1), \quad (\text{eqn. 18})$$

where gfb may have a value of 0.04. The value for gfb may be selected experimentally with considerations, for example, that a high value of gfb may cause feedback loop instability, and a low value of gfb may substantially reduce or eliminate feedback action.

[65] Upon generating 502 or generating 504 the feedback constant, it is determined 506 whether the total limited-bandwidth RO channel energy, E_{OUTR_Lim} , is greater than the total limited-bandwidth RI channel energy, E_{INR_Lim} . Where it is determined 506 that the total limited-bandwidth RO channel energy is not greater than the total limited-bandwidth RI channel energy, a right-channel feedback constant fbr may be generated 510 by the controller 106 as

$$fbr = 0.98 * fbr. \quad (\text{eqn. 19})$$

A value for fbr may be initially set as one. However, where it is determined that the total limited-bandwidth RO channel energy is greater than the total limited-bandwidth RI channel energy, the right-channel feedback constant fbr may be generated 508 by the controller 106 as

$$fbr = 0.98 fbr + gfb ((E_{OUTR_Lim} / E_{INR_Lim}) - 1). \quad (\text{eqn. 20})$$

[66] Although not shown, it will be apparent that the total limited bandwidth LO channel energy, the total limited bandwidth RO channel energy, the total limited-bandwidth LI energy and/or the total limited-bandwidth RI energy may be filtered, for example, low-pass filtered, before determining one or both of the feedback constants fbl and fbr . The filtering may be accomplished at the controller 106, for example, as low-pass filtering. The low pass filtering may utilize, for example, a 70 ms time constant. Other time constants may be utilized. Further, it will be apparent that at least some of the filtering may not be carried out by the controller 106, but rather the filtering may be accomplished by one or more filters embodied as hardware devices.

[67] Returning to Figure 3, upon determining 302 the feedback constant(s), one or more test mix coefficients may be generated 304 by the controller 106 as described with respect to the flowchart of Figure 6. As shown in Figure 6, a test left channel mix coefficient ml' may be generated 600 by the controller 106 as

$$ml' = 0.71 + fbl * lf + fbr * rf, \quad (\text{eqn. 21})$$

where fbl and fbr have values as determined above with respect to Figure 5, lf has a value of -1 and rf has a value of 0.3. The values for lf and rf may be used to bias the test mix coefficients ml' and mr' respectively. The test mix coefficients may be biased using lf and rf , for example, to compensate for a subtle error in localization (i.e., intended direction) when a three channel signal is downmixed and reproduced through two channels. Other values for lf and rf may be utilized.

[68] After generating 600 a value for the test left channel mix coefficient ml' , the value for the test mix coefficient ml' may be limited 602 to a value between 0 and 1. For example, where ml' is determined to be less than 0, ml' is set to a value of 0, and where ml' is determined to be greater than 1, ml' is set to a value of 1.

5 [69] A test right channel mix coefficient mr' may then be generated 604 by the controller 105 as

$$mr' = .71 + fbl * rf + fbr * lf, \quad (\text{eqn. 22})$$

where fbl , fbr , rf and lf have values as discussed above with respect to the generating 600.

[70] After generating the test mix coefficient mr' , a value for mr' may be limited 10 606 to a value between 0 and 1. For example, where the test mix coefficient mr' is determined to be less than 0, mr' may be set to a value of 0, and where the test mix coefficient mr' is determined to be greater than 1, mr' may be set to a value of 1.

[71] The test mixer down mixer left and right mix coefficients ml' and mr' have been determined, for example, using the feedback constant fb , to substantially preserve the 15 energy and intended direction of the limited-bandwidth input signal received at the test down mixer 104 in the output signal of the test mixer. As energy and intended direction are substantially preserved at the test downmixer 104 using the test mix coefficients, the test mix coefficient values, if used in the full-bandwidth downmixer 102, will allow the energy and intended direction of the input signal at the full-bandwidth downmixer to be substantially 20 preserved in the output signal. The test mix coefficients values ml' and mr' may be used to update 608 the mix coefficient values ml and mr used in the full-bandwidth downmixer 102.

[72] The updating 608 may be accomplished by the controller 106 updating the left channel mix coefficient ml of the first mixer 102 with the value of the test left channel mix coefficient ml' , by replacing the value of ml with the value of ml' . Similarly, the right 25 channel mix coefficient mr may be updated by the controller 106 updating the right channel mix coefficient mr of the second mixer 104 with the value of the test right channel mix coefficient mr' , by replacing the value of mr with the value of mr' .

[73] In addition, or in the alternative, the left and right channel mix coefficients may be updated 608 by the controller 106 by smoothing the mix coefficients before they are 30 used in the full-bandwidth downmixer that actually produces to output signals. This smoothing may occur in the time between calculation of new values for ml and mr . For

example, about every one-half of a millisecond the value of m_l in the full bandwidth downmixer may be altered (i.e., updated) in such a way as to bring it closer to the calculated value m_l' . The change is made so that the value of m_l' is reached by m_l in the full bandwidth downmixer before another value of m_l' is determined at the test downmixer 104. The same
5 may be true with respect to updating the mix coefficient value m_r with the test mix coefficient value m_r' .

[74] In this way, the left and right channel mix coefficients m_l and m_r may be generated 304 for the full-bandwidth downmixer 102.

[75] Figure 7 is a graph of mix coefficients that may be generated by the
10 downmixer 100 in accordance with the flow charts of Figures 4-6 for a single input signal presented to the CI and LI channels. The graph of Figure 7 is generated by the single signal panned smoothly between the LI and CI channels, where the intended direction of the input signal is precisely known. Figure 8 is a graph of mix coefficients as a function of panning angle derived experimentally to compensate for a subtle error in localization when a three
15 channel signal is downmixed and reproduced through two channels. The graph of Figure 8 illustrates a calculated ideal case, where there is a single signal panned smoothly between the LI and CI channels, and where the intended direction of the input signal is precisely known. Left channel mix coefficient m_l values are designated in Figures 9 and 10 using a dashed line,
and right channel mix coefficient m_r values are designated in Figures 9 and 10 using a solid
20 line.

[76] It will be apparent that mix coefficients, for example, m_l and m_r , may be generated 202 (Figure 2), as predetermined values responsive to input channel energy, and need not be generated in real-time. Such a scheme may utilize frequency limited input and output energy from a test downmixer as inputs to one or more one-dimensional or two-
25 dimensional look-up tables. As is apparent from the preceeding explanation for the operation of a downmixer, the mix coefficient may depend on the ratio of input energy to the output energy. Look-up tables where the input to the table is the output/input energy ratio as determined by a test downmixer may be used to derive mix coefficients such as m_l and m_r directly.

[77] To generate the predetermined mix coefficients stored in such look-up tables,
30 for example, the mix coefficients m_l and m_r , the controller 106 and a downmixer, for example, the downmixer 102 or the test downmixer 104 may be utilized, where an input

signal for a particular input signal scenario (i.e., having characteristics of a smooth pan from CI to LI, for example as was used to generate the graph of Figure 8) may be processed by the downmixer to determine a ratio between an output energy and an input energy resulting from the input signal scenario. The downmixer and controller 106 may then be utilized to
5 determine at least one mix coefficient, for example, the mix coefficients m_l and m_r that may be utilized with the particular input signal scenario such that signal energy in an intended direction of the input signal is substantially preserved at the output (downmixed) signal. The mix coefficients may be generated, for example, as discussed above with respect to Figures 4-6.

10 [78] The ratio between the output and input energies for that particular input signal scenario may be stored in a tabular format at the storage device 120. Such a tabular format may include, for example, the mix coefficients m_l and m_r indexed by the ratio of output to input energy for one or more input signal scenarios. For example, a mix coefficient table for m_l may be provided, and indexed by a ratio of output to input signal energy for particular
15 input signal scenarios. Similarly, a mix coefficient table for m_r may be provided and indexed by the ratio between output and input signal energy for the particular scenario.

[79] In operation, the controller 106 may detect a particular input signal scenario, determine a ratio between output and input energies, and based on the ratio, lookup values for at least one mix coefficient, for example, the mix coefficients m_l and m_r to be used by the
20 downmixer to downmix the signal for that input signal scenario. The mix coefficient(s) retrieved allow that input energy and intended direction of the input signal to be substantially preserved at the output signal. The controller may update mix coefficient values in the downmixer with the retrieved mix coefficient values, for example, in a similar fashion as discussed above with respect to the updating 608 of Figure 6.

25 [80] In this way, a library of predetermined mix coefficient scenarios may be determined, and for example, stored at the storage device 120. The library may include mix coefficient tables for mix coefficients, where, for example, each mix coefficient table provides one or more mix coefficients indexed by a ratio of output to input energy. Other mix coefficient table configurations may be possible. The mix coefficient library may be
30 accessed by the controller in retrieving mix coefficient values for a particular input signal scenario.

[81] The predetermined mix coefficient generation may be utilized in conjunction with the mix coefficient generation generation described above with respect to Figures 6 – 8. For example, the controller may attempt to identify whether the input signal meets requirements for a particular input signal scenario for which the mix coefficient library includes a predetermined mix coefficient(s). Where the controller 106 determines that the input signal fits one of the input signal scenarios for which mix coefficients are stored, the controller may generate mix coefficients by retrieving appropriate mix coefficients from the mix coefficient library as described above. However, where the controller 106 determines that the input signal does not meet criteria for a stored input signal scenario, the controller may, in conjunction with the test mixer 104, generate mix coefficients for the downmixer.

[82] Additionally, or in the alternative, the controller may employ a learning algorithm, allowing it to identify characteristics for input signal scenarios, for which predetermined mix coefficients would be useful (i.e., input signal scenarios that are repeatedly received in an input signal at the downmixer). In such circumstances, the controller may be capable of using the test downmixer to determine mix coefficient values for the particular input signal scenario, and stored in the storage device 120. Upon subsequent recognition of the input signal scenario, the controller 106 may generate mix coefficients for the scenario by retrieving the mix coefficients from the mix coefficient table.

[83] By generating mix coefficient values by retrieving mix coefficients as described above, the controller may generate mix coefficient values that may allow input signal energy and intended direction to be preserved in the output signal with less of a demand on downmixer resources than may be required to generate the mix coefficients as described above with respect to Figures 4-6. Downmixer resources may be freed-up for use by the downmixer in other operations.

[84] Figure 9 is a block diagram of a downmixer 900 in accordance with the invention. The downmixer 900 is capable of receiving a multi-channel input signal including more than two channels and down-mixing the multi-channel input signal to an output signal including a number of channels less than the number of channels of the input signal. The downmixer 900 includes a full-bandwidth downmixer 901 for downmixing the 5.1 channel input signal to the two-channel output signal utilizing at least one of the front channel left and right mix coefficients m_l and m_r , and the surround channel mix coefficients m_i and m_s , such that the energy and intended direction of the input signal is substantially preserved in the

output signal. The downmixer 900 further includes a test downmixer 104' which may be utilized in conjunction with a controller 940 in generating front channel left and right mix coefficients m_l and m_r . As the front channel mix coefficients m_l and m_r may be generated in a similar fashion as the mix coefficients m_l and m_r by the test mixer 104 and controller 106 of Figure 1, operation of the test mixer 104' will not be discussed in detail. The downmixer 900 may further include a test downmixer 950 which may be utilized with the controller 940 in generating one or more of the surround mix coefficients, for example, the surround mix coefficients m_i and m_s , such that signal energy and intended direction of the input signal is substantially preserved in the output signal of the full-bandwidth downmixer 901.

[85] As shown in Figure 9, a front left input (LI), front center input (CI), front right input (RI), low frequency (LFE), left surround input (LSI) and right surround input (RSI) channels may be received at the downmixer 900. The downmixer 900 is capable of down mixing the 5.1 input channels of the input signal to an output signal including, for example, two output channels, a left output (LO) and right output (RO) channel.

[86] The full-bandwidth downmixer 901 may include a first LI mixer 902 for mixing the LI, CI and LFE channels and a first RI mixer 904 for mixing the RI, CI, and LFE input channels of the input signal. Multipliers 906 and 908 may be utilized to multiply the CI input signal by respective front left and right channel mix coefficients m_l and m_r before mixing the CI channel at the first LI mixer 902 and first RI mixer 904. A second LI mixer 910 may allow components of one or both surround channels LSI and RSI to be added to the LI' channel information, and a LI phase shifter 912 may be provided to accomplish any desired phase shift to form LO' channel information. Similarly, a second RI mixer 914 may be provided for adding components of one or both surround channels LSI and RSI to the RI' channel information, and a RI phase shifter 916 may be provided to accomplish any desired phase shift to form RO' channel information.

[87] An LSI mixer 918 may be provided to add a component of the RSI channel to the LSI channel, and a multiplier 922 may be provided for accounting for a LSI mix coefficient, for example a m_i surround mix coefficient corresponding to an imaginary component LSI' of the LO channel. A LSI phase shifter 924 may be provided to accomplish any desired phase shift to the LSI' channel information to form the LSO' channel information. Similarly, a RSI mixer 930 may be provided for adding a component of the LSI channel to the RSI channel, a multiplier 932 allows for the m_i surround mix coefficient to be

accounted for, and a RSI phase shifter 934 may be utilized to provide any desired phase shift to the RSI' channel information to form RSO' channel information.

[88] Multipliers 919 and 921 may be provided to account for a ms surround mix coefficient. For example, the ms' surround mix coefficient may be utilized to control an amount of the LSI and RSI channels that are added to the respective front channel output path, for example, to the LI' and LO' signals, respectively.

[89] A LO mixer 936 may be provided to mix the LSO' and LO' channel information to form an output channel LO of the output signal. Similarly, a RO mixer 938 may be utilized to mix the RO' and RSO' channel information to form the RO output channel of the output signal.

[90] The test downmixer 950 may include a first test adder 952 and a second test adder 954. The first test adder 952 is coupled with a first test mixer 956 and a second test mixer 958, to account for test surround mix coefficients mi' and ms' at the test mixer 950. Similarly, the second test adder 954 is further coupled with a third test mixer 960 and a fourth test mixer 962 capable of accounting for the test surround mix coefficients ms' and mi' respectively in the test downmixer 950.

[91] The controller 940 may be coupled with one or more of the input channels, for example, the LSI, LI, CI, LFE, RI and RSI input channels, as well as with one or more of the multipliers 906, 908, 919, 921, 922 and 932 of the full-bandwidth downmixer 901, for generating and/or updating one or more of the mix coefficients ml , mr , ms , and mi , utilizing the test downmixers 140' and 950. To reduce confusion, the coupling between the controller 940 and the multipliers 906, 908, 919, 921, 922 and 932 are shown with dotted lines.

[92] The first test adder 952 is capable of receiving a limited-bandwidth (i.e., filtered) LSI channel information as LSI_{Lim} , received at the test downmixer 950 and attenuated by a factor of 0.91. The first test adder 952 is further capable of receiving a RSI limited-bandwidth channel information as RSI_{Lim} that has been inverted, and multiplied by a cross-correlation factor-0.38, and adding that with the attenuated LSI_{Lim} signal. The resulting channel information from the first test adder 952 may then be mixed at the first and second test mixers 956 and 958 in accordance with test surround mix coefficients mi' and ms' , to generate test mixer 950 output channel information $LSO-Im_{Lim}$ and $LSO-Re_{Lim}$ respectively. Similarly, the second test adder 954 may be capable of adding an inverted RSI_{Lim} channel information, attenuated by a factor of 0.91, with LSI_{Lim} channel information that has been

multiplied by a cross-correlation factor -0.38. The resulting channel information may then be mixed at the third and fourth test mixers 960 and 962 in accordance with the test surround mix coefficients ms' and mi' to generate the test mixer 950 output channel information $RSO-Re_{Lim}$ and $RSO-Im_{Lim}$ respectively.

5 [93] The controller 940 may further be coupled with the test downmixer 104', and the first, second, third and fourth test mixers 956, 958, 960 and 962. The controller 940 may be capable of receiving one or more of the LI, CI, RI, LFE, LSI and RSI channel information of the input signal, and determining limited-bandwidth (i.e., filtered) channel information, for example, LSI_{Lim} and RSI_{Lim} for use in the test downmixer 950. The controller 940 may
10 further be capable of receiving output channel information, for example the output channel information LO and RO from the full-bandwidth downmixer 901, and/or the limited-bandwidth output channel information $LSO-IM_{Lim}$, $LSO-RE_{Lim}$, $RSI-RE_{Lim}$ and $RSI-IM_{Lim}$ channel information from the test downmixer 950, and generating one or more mix coefficients, for example, the mix coefficients ml , mr , mi and ms using the test downmixer
15 950, as described below. The controller 940 may further be coupled with a storage device 942 providing a working memory and a program memory for the controller 940. Operation of the downmixer 900 will be discussed with reference to the flow chart of Figure 10.

[94] Figure 10 is a flow chart illustrating operation of the downmixer 900 of Figure 9. As shown in Figure 10, input channel information is received 1000, for example,
20 including information for the LSI, LI, CI, LFE, RI and RSI channels of the input signal. One or more mix coefficients may be generated 1002 using the controller 940 and the test downmixer 950, responsive to at least one of the input channel information as will be described below with reference to Figures 11-13 and 14-17. The LI, CI, LFE and RI channel information, may be mixed 1004 in a similar fashion as discussed above with respect to
25 Figure 3 and Figures 4-6. Further, information of the LFE channel may be amplified, for example, by a factor of two, before being mixed at the first LI and RI mixers 902 and 904, respectively. Additionally, the CI channel information may account for one or more mix coefficients, for example, front left and right channel mix coefficients ml and mr , using the multipliers 906 and 908, before the CI channel information is mixed at the first LI and RI
30 mixers 902 and 904. The first LI mixer 902 generates LI' channel information and the first RI mixer 904 generates RI' channel information. For example, the LI' and RI' channel information may be utilized as a left and right output signal for the purpose of generating the

mix coefficients m_l and m_r , in a similar fashion as discussed above with respect to Figures 3-11.

[95] Components of the LSI and RSI channels may be added 1006 to the LI' and RI' channel information using the second LI mixer 910 and second RI mixer 914, respectively. For example, LSI channel information may be multiplied with a mix coefficient m_s at multiplier 919, before being mixed with the LI' channel information at the second LI mixer 910. Similarly, the RSI channel information may be multiplied by a mix coefficient m_s at a multiplier 919 before being mixed with the RI' channel information at the second RI mixer 914. Any desired phase shift for the front channel information may be provided 1008, by the LI phase shifter 912 and the RI phase shifter 916, to form LO' and RO' channel information respectively.

[96] Concurrently with, or subsequent to the mixing 1004, adding 1006 and providing 1008, components of the RSI and LSI channels may be added 1010 to one another. For example, the RSI channel may be inverted at an inverter 927, and multiplied at a multiplier 928, by a cross-correlation factor, for example, -0.38, and mixed with the LSI channel information at the LSI mixer 918. Before mixing at the LSI mixer 918, the LSI channel information may be attenuated by some factor, for example 0.91 at a multiplier 929. In a similar fashion, a component of the LSI channel may be added to the RSI channel using a multiplier 931, by multiplying the LSI channel information by a cross-correlation factor, for example -0.38, and mixed with the RSI signal at the RSI mixer 930. Before mixing at the RSI mixer, the RSI channel may be attenuated by a factor, for example 0.91, at a multiplier 933.

[97] A respective mix coefficient may be accounted for by multiplying 1012 the channel information from respective LSI mixer 918 and RSI mixer 930 by the mix coefficient m_i to form the LSI' and RSI' channel information respectively.

[98] Any desired phase shift may be provided 1014 for the surround channels. For example, a phase shift may be provided to the LSI' channel information at the LSI phase shifter 924 to form the LSO' channel information, where the phase is offset by 90 degrees with respect to that provided by the LI phase shifter 912. Similarly, the RSI' channel information may be shifted in phase at the RSI phase shifter 934 to form the RSO' channel information, where the phase shift is offset by 90 degrees with respect to that applied by the RI phase shifter 916.

[99] The surround channel information and front channel information may then be mixed 1016. For example, the LSO' channel information may be mixed with the LO' channel information at the LO mixer 936 to form the LO channel of the output signal, and the LO channel may be provided 1018. Similarly, the RSO' channel information may be mixed with the RO' channel information at the RO mixer 938 to form the RO channel of the output signal, and the LO channel may be provided 1018.

[100] Although the generating 1002 mix coefficients has been shown at a particular location in the flow chart of Figure 10, it will be apparent that one or more mix coefficients, for example m_l , m_r , m_i , and m_s may be generated by the controller 940 at any time during operation of the downmixer 900. Further, the mix coefficients need not all be generated at the same time, and may be generated at different times during operation of the downmixer 900. The front left and right channel mix coefficients m_l and m_r may be generated using the controller 940 and the test downmixer 104' in a similar fashion as discussed above with respect to Figure 3 and Figures 4-6, and will not be discussed in detail. In addition, the mix coefficient generation for the front channel mix coefficients m_l and m_r may be accomplished independently from the mix coefficient generation of the surround mix coefficients m_i and m_s .

[101] The generation of the surround mix coefficients m_i and m_s may be generated by the controller 940 using the test mixer 950, for example, as discussed with respect to the flow chart of Figure 3, and the flow charts of Figures 11-13 and 14-17. As shown in Figure 3, at least one of an input and an output channel energy is determined 300. At least one of the input and output channel energy determination 300 will be discussed with respect to the flow chart of Figure 11.

[102] Figure 11 is a flow chart illustrating operation of the controller 940 in determining input channel energy, used in generation of at least one test surround mix coefficient, for example, test surround mix coefficients m_i' and m_s' . As shown in Figure 11, input channel information for the LSI and RSI channels are received 1100 at the controller 940, for example as signal samples of the input signal, in a similar fashion as discussed above with respect to the receiving 400 of Figure 4.

[103] The input channel information may be filtered 1102 by the controller 940 to generate limited-bandwidth input channel information LSI_{Lim} and RSI_{Lim} channel information. For example, the input channel information may be filtered 1102 utilizing a

finite impulse response filter, for example, emphasizing frequencies and the 700-4000 Hz frequency range, in a similar fashion as discussed above with respect to filtering 402 of Figure 4.

[104] Limited-bandwidth output channel information may be determined 1104 at the test downmixer 950 as LSO real and imaginary channel information, $LSO-Re_{Lim}$ and $LSI-Im_{Lim}$, and RSO real and imaginary channel information, $RSO-Re_{Lim}$ and $RSO-Im_{Lim}$, as

$$LSO-Re_{Lim} = ms' * LSI_{Lim} \quad (\text{eqn. 23})$$

$$LSO-Im_{Lim} = mi' * (0.91 * LSI_{Lim} + .38 * RSI_{Lim}) \quad (\text{eqn. 24})$$

$$RSO-Re_{Lim} = ms' * RSI_{Lim}, \text{ and} \quad (\text{eqn. 25})$$

$$RSO-Im_{Lim} = mi' * (-.91 * RSI_{Lim} - .38 * LSI_{Lim}), \quad (\text{eqn. 26})$$

where ms' and mi' are initialized to a value of 0.7. A limited-bandwidth input channel energy may be determined 1106 by the controller 940 for LSI energy and RSI energy, as $ELSI_{Lim}$ and $ERSI_{Lim}$, respectively, where

$$ELSI_{Lim} = ELSI_{Lim}^2 \text{ and} \quad (\text{eqn. 27})$$

$$ERSI_{Lim} = ERSI_{Lim}^2. \quad (\text{eqn. 28})$$

[105] Limited-bandwidth output channel energy may be determined 1108 by the controller 940, as real and imaginary components of LSO channel energy, $ELSO-Re_{Lim}$ and $ELSO-Im_{Lim}$, respectively, and real and imaginary of RSO channel energy, $ERSO-Re_{Lim}$ and $ERSO-Im_{Lim}$, respectively, where

$$ELSO-Re_{Lim} = LSO-Re_{Lim}^2 \quad (\text{eqn. 29})$$

$$ELSO-Im_{Lim} = LSO-Im_{Lim}^2 \quad (\text{eqn. 30})$$

$$ERSO-Re_{Lim} = RSO-Re_{Lim}^2, \text{ and} \quad (\text{eqn. 31})$$

$$ERSO-Im_{Lim} = RSO-Im_{Lim}^2. \quad (\text{eqn. 32})$$

[106] The limited-bandwidth input and output channel energy may be averaged 1110 by the controller 940 in a similar fashion as discussed above, for example, with respect to the averaging 410, as LSI, RSI, LSO and RSO average energy $ELSI_{Sum}$, $ERSI_{Sum}$, $ELSO_{Sum}$, and $ERSO_{Sum}$, respectively, where

$$ELSI_{Sum} = ELSI_{Sum} + ELSI_{Lim} \quad (\text{eqn. 33})$$

$$ERSI_{Sum} = ERSI_{Sum} + ERSI_{Lim} \quad (\text{eqn. 34})$$

$$ELSO_{Sum} = ELSO_{Sum} + ELSO-Re_{Lim} + ELSO-Im_{Lim}, \text{ and} \quad (\text{eqn. 35})$$

$$ERSO_{Sum} = ERSO_{Sum} + ERSO-Re_{Lim} + ERSO-Im_{Lim}. \quad (\text{eqn. 36})$$

[107] It may be determined 1112 whether the averaging is complete. Where the averaging is not complete, flow returns to the receiving 1100. Where it is determined 1112 that the averaging is complete, a total limited-bandwidth input and output channel may be determined 1114 by the controller as E_{InLim} and E_{OutLim} , respectively, as

$$E_{InLim} = E_{LSISum} + E_{RSISum}, \text{ and} \quad (\text{eqn. 37})$$

$$E_{OutLim} = E_{LSOSum} + E_{RSOSum}. \quad (\text{eqn. 38})$$

[108] Returning to Figure 3, upon determining 300 at least one of the input and output channel energy, a feedback constant may be determined 302. The determining 302 of the feedback constant will be discussed with respect to the flow chart of Figure 12.

[109] Figure 12 is a flow chart illustrating operation of the controller 940 in determining a feedback constant $fbsi$ that may be used in determining a test mix coefficient(s) for the test downmixer 950, for example, the test surround channel mix coefficients mi' and ms' . As shown in Figure 12, the limited-bandwidth input and output energy, for example, determined at 1114, may be filtered 1200 by the controller 940 to form filtered input and output limited-bandwidth energy SIN_{Lim} and $SOUT_{Lim}$, as

$$SIN_{Lim} = .98 * SIN_{Lim} + .02 * E_{InLim}, \text{ and} \quad (\text{eqn. 39})$$

$$SOUT_{Lim} = .98 * SOUT_{Lim} + .02 * E_{OutLim}. \quad (\text{eqn. 40})$$

Such filtering may be low pass filtering, and may be accomplished utilizing a filter having, for example a 70ms time constant. Other time constants may be utilized.

[110] A feedback constant $fbsi$ may be determined 1202 by the controller 940, as

$$fbsi = .98 * fbsi + gfb * ((SOUT_{Lim} / SIN_{Lim}) - 1), \quad (\text{eqn. 41})$$

where gfb has a value of 0.04. Considerations for a value of gfb to be used may be similar to as discussed above with respect to the generation 504 discussed above with respect to Figure 5. Upon determining 302 the feedback constant, one or more test surround mix coefficients may be generated 304 by the controller 940, as will be described with respect to Figure 13.

[111] Figure 13 is a flow chart illustrating operation of the controller 940 when generating test surround mix coefficients for the downmixer 900, for example the test surround channel mix coefficients mi' and ms' . As shown in Figure 13, it is determined 1300 whether a value of the feedback constant $fbsi$, determined at 1202, is greater than or equal to zero. Where the feedback constant is not greater than or equal to zero, a value of the test surround mix coefficient ms' is set by the controller 940 at 1302, to a value of

$$ms' = 0 - fbsi, \quad (\text{eqn. 42})$$

and a value of the test mix coefficient mi' is set at 1304 to a value of 1. However, where it is determined 1300 that the feedback constant is greater than or equal to zero, a value of ms' is set at 1306 to zero and at 1308, a value of mi' is set to

$$mi' = 1 - fbsi. \quad (\text{eqn. 43})$$

Where mi' is less than zero, mi' is reset at 1310 to a value of zero.

[112] After generating the test mix coefficients mi' and ms' , the test surround mix coefficients mi' and ms' may be utilized by the controller to update the surround mix coefficients mi and ms used by the full-bandwidth downmixer 901. The updating 1312 may be accomplished in a similar fashion as described above, for example with respect to the updating 608 of Figure 6.

[113] The mix coefficient mi may be utilized in the downmixer 900 to attenuate one or both of the surround channels, for example, when the LSI or RSI channels are driven together by the same signal. The surround mix coefficient mi may be adjusted by a small feedback loop to keep the input power and the output power substantially equal. The surround mix coefficient ms may be utilized, for example, to bypass the 90 degree phase shifters 924 and 934, where ms may control an amount of cross-mixed surround signal that is added to the front channels, for example, in situations where LSI and RSI are out of phase. Where ms has a positive, non-zero value, a coherent signal of the surround input channels may be provided in both the 90 degrees phase-shifted path and the non-90 degree phase shifted path of the downmixer 900.

[114] In at least some circumstances, it may be desirable to make modifications/adjustments to one or more of the surround mix coefficients, for example the surround mix coefficients mi and ms determined with respect to Figure 13, before or during the time they are used by the downmixer 900. As with the generating of the front channel mix coefficients ml and mr , the surround channel mix coefficient(s) mi and ms are typically generated in a test downmixer environment. By utilizing the test downmixer for generating one or both of the mix coefficients mi and ms , the coefficients may be additionally modified/adjusted before being used in a full frequency range downmixer, where values for mi and ms may be kept in the test downmixer to not disturb the feedback.

[115] Values of one or both of the surround mix coefficients mi and ms may be adjusted to create a two-channel downmix that is subjectively closer to the original five-

channel downmix by altering an energy ratio between the front channels and the rear channels in an active manner. Such modifications may adjust for a situation where there is too much reverberation in the surround channels. A ratio of the energy in the front channels and the surround channels, F/S, may be utilized to adjust the mix coefficients m_i and m_s . The adjustments may include reducing at least one or both of m_i and m_s by some amount, for example, corresponding to 3dB of the LSI and/or RSI channel information, where a F/S ratio is greater than 1, as discussed below. Further, in some situations, it may be desirable to actively look for audible sound elements (i.e., non-reverberation sound information) in one or more of the input channels, for example, in one or both of the surround channels LSI and RSI. When audible sound elements are present, the 3dB attenuation applied to the mix coefficients m_i and m_s may be removed.

[116] In addition, the surround mix coefficients m_i and m_s may be adjusted to enhance various sound events, for example, to emphasize surround channel signals that may not be as strong as simultaneous signals occurring in the front channels received at the downmixer 900. A sound event may be thought of as a directional transient, for example, sounds that have an initial energy spike, such as a shout or a drum hit, and where information about the transient direction is maintained (i.e., not blocked by an object). Two types of sound events may be syllables and impulsive sounds. Syllables may include phonemes and notes. Phonemes are transient sounds that are characteristic of phones in human speech and that can be particularly useful in detecting and localizing syllables in human speech. Notes are individual notes created by a musical instrument. Because notes and phonemes have a common characteristic, they may be collectively referred to as "syllables". Syllables, generally have the following characteristics: a finite duration of approximately at least 50 ms up to approximately 200 ms, but typically around 150 ms; rise times of approximately 33 ms; generally occur no more frequently than approximately once every 0.2 ms to approximately 0.5 ms; and may have low or high volume (amplitude). In contrast, impulsive sounds may be transients of very short duration such as a drum hit or fricatives, and explosives in speech. Impulsive sounds generally have the following characteristics: a short duration of approximately 5 ms to approximately 50 ms, rise times of approximately 1 ms to approximately 10 ms, and a high volume.

[117] A sound event may be detected, for example, as described in commonly-assigned U.S. Patent Application No. (not yet assigned), entitled "Sound Event Detection", to

David H. Griesinger, filed May 2, 2003 as Attorney Docket No. 11336/208, and is incorporated by reference herein. For example, a rate of increase in an input energy level at one of the input channels may be utilized to detect the start of a sound event. For example, a rate of increase in one or both of the LSI and RSI channels may be detected, where a value of the mix coefficients m_i and/or m_s may be adjusted to allow the sound event to be more prominent in the two channel mix than if signal power were completely preserved. For example, any 3dB attenuation applied to combat a detected reverberation signals in one or more of the input channels may be removed. The sound event detector may be utilized in conjunction with any of the input channels, and the presence of a significant sound event in a particular input channel may be used to trigger a temporary boost of the level in that channel. The boost may be accomplished by increasing a value for one or more mix coefficients, for example, the mix coefficients m_i and m_s . Such a boost may last, for example, 100 to 300 ms. Further, the boost may be, for example, a boost corresponding to a gain of 1 - 3dB of the corresponding channel information for enhancing the audibility of low level sound events in the resulting downmix.

[118] Figures 14-17 are flowcharts illustrating adjustment of surround mix coefficient(s).

[119] Figure 14 is a flowchart illustrating operation of the controller 940 in adjusting one or more mix coefficients, for example, the surround mix coefficients m_i and m_s . As shown in Figure 14, input channel energy is determined 1400. The determining 1400 of the input channel energy is discussed below with respect to the flowchart of Figure 15. Upon determining 1400 the input channel energy, one or more mix coefficients, for example m_i and m_s , may be adjusted 1402. Mix coefficient adjusting 1402 is discussed below with respect to the flowcharts of Figures 16-17.

[120] Figure 15 is a flowchart illustrating operation of the controller 940 in determining 1400 the input channel energy. Input channel information is received 1500, and may include information regarding the LI, RI, CI, LSI, and RSI channels of the input signal. A front input channel energy may be determined 1502 for the LI, CI, and RI channels as ELI , ECI , and ERI , where

$$ELI = LI^2 \quad (\text{eqn. 44})$$

$$ECI = CI^2, \text{ and} \quad (\text{eqn. 45})$$

$$ERI = RI^2. \quad (\text{eqn. 46})$$

[121] The IP channel information may be received 1500 in a similar fashion as discussed above with respect to the receiving 400 of Figure 4. A total front input channel energy may be determined 1504 as EFI , where

$$EFI = ELI + ECI + ERI. \quad (\text{eqn. 47})$$

[122] A surround input channel energy may be determined 1506 for a LSI channel and a RSI channel as $ELSI$ and $ERSI$ respectively, where

$$ELSI = LSI^2, \text{ and} \quad (\text{eqn. 48})$$

$$ERSI = RSI^2. \quad (\text{eqn. 49})$$

[123] A total surround input channel energy, ESI , may be determined 1508, as

$$ESI = ELSI + ERSI. \quad (\text{eqn. 50})$$

[124] The front and surround input channel energy may be averaged 1510 as EFI_{Sum} and ESI_{Sum} , respectively, where

$$EFI_{\text{Sum}} = 0.9 * EFI_{\text{Sum}} + 0.1 * EFI, \text{ and} \quad (\text{eqn. 51})$$

$$ESI_{\text{Sum}} = 0.9 * ESI_{\text{Sum}} + 0.1 * ESI. \quad (\text{eqn. 52})$$

[125] The averaging 1510 may be accomplished in a similar fashion as discussed above, for example, with respect to the averaging 410 of Figure 4.

[126] It may be determined 1512 whether the averaging is complete. Where the averaging is not complete, the flow returns to the receiving 1500 input channel information and continues as discussed above. Where it is determined 1512 that the averaging is complete, the front and surround input channel averages are filtered 1514 as EFI_{Lim} and ESI_{Lim} , where

$$EFI_{\text{Lim}} = 0.99 * EFI_{\text{Lim}} + 0.01 * (EFI_{\text{Sum}}), \text{ and} \quad (\text{eqn. 53})$$

$$ESI_{\text{Lim}} = 0.97 * ESI_{\text{Lim}} + 0.03 * (ESI_{\text{Sum}}). \quad (\text{eqn. 54})$$

[127] Once the input channel energy is determined 1400, the mix coefficients may be adjusted 1402 as described with respect to the flowcharts of Figures 16 and 17.

[128] Figure 16 is a flowchart illustrating operation of the controller 940 in adjusting 1402, one or more mix coefficients, for example the surround mix coefficients mi and ms . As shown in Figure 16, a surround energy boost factor, SBF , may be generated 1600 as

$$SBF = 3 * ESI - 2 * ESI_{\text{Lim}}. \quad (\text{eqn. 55})$$

[129] It may then be determined whether the average surround energy, ESI_{Lim} , is rising. This is accomplished by determining 1602 whether the average surround energy is less than the surround energy boost factor. Where it is determined that the average surround

energy is less than the surround energy boost factor, the average surround energy may be averaged 1604 using a first time constant, for example as

$$ESI_{Sum} = 0.99 * ESI_{Sum} + 0.01 * SBF. \quad (\text{eqn. 56})$$

The first time constant may be, for example, approximately 150 ms.

[130] However, where it is determined 1602 that the average surround energy is not less than the energy boost factor, the average surround energy may be averaged 1606 using a second time constant, as

$$ESI_{Sum} = 0.999 * ESI_{Sum} + 0.001 * SBF, \quad (\text{eqn. 57})$$

where the second time constant may be, for example, approximately, 1.5 seconds.

[131] The average surround input energy may then be averaged responsive to a current value of the surround input energy. This may be accomplished, for example, by steps 1602, 1604, and 1606.

[132] A front/back energy ratio, F/S, may be determined 1608 as an energy ratio between the average front channel and average surround channel input energies, as

$$F/S = (EFI_{Sum} + 1) / ((1.2 * ESI_{Sum}) + 1). \quad (\text{eqn. 58})$$

The front/surround energy ratio may be a bias to the surround input channel, by for example, 1.2 dB. Further, the front/surround energy ratio may be constrained within a range of 0.1 and 10. For example, where the front/surround power ratio is greater than 10, the front/surround energy ratio may be set to a value of 10. Where the front/surround energy ratio is less than 0.1, the front/surround energy ratio may be set to a value of 0.1.

[133] The mix coefficients m_i and m_s may determined responsive to the front/surround energy ratio. This may be accomplished by determining 1610 whether the front/surround energy ratio is greater than a value of 4. Where the front/surround energy ratio is greater than 4, the mix coefficients m_s and m_i may be set at 1612 and 1614 to

$$m_s = 0.71 * m_s, \text{ and} \quad (\text{eqn. 59})$$

$$m_i = 0.71 * m_i. \quad (\text{eqn. 60})$$

[134] However, where it is determined 1610 that the front/surround energy ratio is not greater than 4, it may be determined 1616 whether the front/surround energy ratio is greater than or equal to a value of 2, and less than or equal to a value of 4. If the front/surround energy ratio is greater than or equal to 2 and less than or equal to 4, the mix coefficients m_s and m_i may be set 1618 and 1620, respectively, as

$$m_s = 0.8 - 0.045 * (F/S - 2), \text{ and} \quad (\text{eqn. 61})$$

$$m_i = 0.8 - 0.045*(F/S-2). \quad (\text{eqn. 62})$$

[135] If however, it is determined 1616 that the front/surround energy ratio is not greater than or equal to 2 and less than or equal to 4, the mix coefficients m_s and m_i may set 1622 and 1624, as

$$m_s = 1-0.2*(F/S-1), \text{ and} \quad (\text{eqn. 63})$$

$$m_i = 1-0.2*(F/S-1). \quad (\text{eqn. 64})$$

[136] Further, the values for the mix coefficients, for example the surround mix coefficients m_i and m_s may be adjusted responsive to an increase in surround channel input levels as a surround channel level increase ratio, S/I . Adjustments to the mix coefficients m_i and m_s responsive to the rear surround channel input level is discussed with respect to the flowchart of Figure 17.

[137] Figure 17 is a flowchart illustrating operation of the controller 940 in adjusting one or more mix coefficients, for example the surround mix coefficients m_i and m_s , in response to a rear surround input energy level ratio S/I . As shown in Figure 17, a rear surround input energy ratio, S/I , is generated 1700, where

$$S/I = \text{SBF}/\text{ESI}_{\text{Lim}}, \quad (\text{eqn. 65})$$

where the surround energy boost factor is as determined with respect to Figure 16, and the ESI_{Lim} is as determined with respect to Figure 15. It is then determined 1702 whether a second surround boost factor indicators, SBF_2 is less than the surround input energy ratio.

Where the second boost factor is less than the energy ratio, the second surround boost factor is set 1704 as

$$\text{SBF}_2 = 0.8\text{SBF}_2 + 0.2 S/I, \quad (\text{eqn. 66})$$

[138] However, where the second surround boost factor is not less than the surround input energy ratio, the second surround boost factor indicator may be set 1706 as

$$\text{SBF}_2 = 0.97\text{SBF}_2 + 0.03S/I \quad (\text{eqn. 67})$$

where the second surround boost factor 1704 represents a time constant of approximately 7 ms, and the second boost factor at 1706 represents a time constant of approximately 70 ms.

[139] The second surround boost factor indicator may be scaled responsive to F/S . This is accomplished, by determining 1708 whether F/S is less than 0.6. Where F/S is less than 0.6, the surround boost factor indicator SBF may be scaled as

$$\text{SBF}_2 = \text{SBF}_2*(S/I*1.8). \quad (\text{eqn. 68})$$

However, where it is determined 1708 that F/S is not less than 0.6, it may be determined 1712 whether F/S is greater than 1.8. Where F/S is greater than 1.8, the second surround boost factor may be scaled 1714 as

$$SBF2 = SBF2/(S/I*0.6). \quad (\text{eqn. 69})$$

[140] Where the second surround boost factor has been scaled 1710 or 1714, or where it is determined 1712 that F/S is not greater than 1.8, it may be determined 1716 whether the F/S is greater than 1.3. Where it is determined 1716 that the F/S is greater than 1.3, the second surround boost factor may be scaled 1718 to a value of 1.3. Where the second surround boost factor is scaled 1718, or where the F/S is determined not to be greater than 1.3, it may be determined 1720 whether the F/S is greater than 1.

[141] Where it is determined 1720 that the F/S is greater than 1, the second surround mix coefficients m_s and m_i may be set 1722 and 1724 as

$$m_s = m_s * SBF2, \text{ and} \quad (\text{eqn. 70})$$

$$m_i = m_i * SBF2. \quad (\text{eqn. 71})$$

[142] Where the surround mix coefficients m_s and m_i have been set 1722 and 1724 or where it is determined 1720 that the F/S is not greater than 1, flow may return to the receiving input channel information 1100 and continue as discussed with respect to Figure 11.

[143] Although the adjustment/modification to mix coefficients has been discussed as occurring after generating mix coefficients that may be utilized in a downmixer for substantially preserving energy and intended direction of an input signal at the output signal, it will be apparent that the mix coefficient adjustments discussed with respect to Figures 14-16 may be made independent of mix coefficient generation discussed with respect to Figures 4-6 and/or Figures 11-13. Further, the mix coefficient adjustments made with respect to Figures 14-17 may be made at particular intervals, for example, at every 64 samples of audio signal information processed at the downmixer, where, for example, an overall sampling rate of the input signal is 44,100 samples per second. Other particular periods may be utilized for adjusting/modifying mix coefficients. Further, the downmixer may be capable of processing audio signals at sampling rates other than 44,100 samples per second.

[144] Although the downmixers 100 and 900 have been described as downmixers or downmixing input signals having 3 input channels and 5.1 input channels to output signals having 2 output channels respectively, it will be apparent that the teachings described above

may be applied to a downmixer for mixing an input signal having any number of input channels to an output signal having a number of output channels less than the number of input channels. The downmixers 100 and 900 may be implemented on one or more microprocessors executing suitable programmed code stored in internal memory of the microprocessor and/or the storage device 120 and 942 respectively. For example, the microprocessor(s) may be sufficiently programmed for, and possess processing capabilities and other hardware requirements, for allowing the microprocessors to provide the functionalities described herein with respect to the downmixers 100 and 900. Further, the microprocessors may be capable of providing any digital signal processing, filtering or other functionalities in carrying out the downmixing described herein.

[145] The test mixers may be utilized in generating mix coefficient values at all times while the downmixer 100 or 900 is operating. The controller, using a test mixer, for example, test mixer 104 or test mixer 950, may constantly monitor input and output energy, and determine one or more mix coefficient values when appropriate to allow signal energy and intended direction of the input signal to be substantially preserved at the output signal. Alternatively, the controller 106 may monitor the input and output signal energies at the full-bandwidth downmixer, and invoke the test downmixer to generate mix coefficient values in circumstances when the full bandwidth output energy is not equal to the full bandwidth input energy.

[146] Although front channel and surround channel mix coefficient values have been described as being generated using test mixers, for example, test mixer 104 and test mixer 950, respectively, it will be apparent that mix coefficient values may be determined using the full-bandwidth downmixer, while the downmixer is downmixing the input signal to the output signal. In this circumstance, a test mixer may not be needed or provided. For example, the controller 106 may determine the input energies of the full-bandwidth input, and full-bandwidth output signals of the full-bandwidth downmixer, and generate and/or update mix coefficient values utilizing this full-bandwidth energy in a similar fashion as described above with respect to Figures 4-6 and 11-13 for limited-bandwidth energies. In addition, although the test downmixer 950 is described as being utilized with a 5.1 to channel downmixer, it will be apparent that the test downmixer 950 may be utilized for generating surround mix coefficient values that may be utilized in any downmixer having surround channel downmixing capabilities.

[147] A downmixer is provided capable of generating mix coefficients such that energy and intended direction of the input signal is substantially preserved at the output signal. Such mix coefficient generation may be accomplished, for example, in a test downmixer, where values for mix coefficients may be updated to a non-test downmixer, for example a full-bandwidth downmixer. The test downmixer may operate on limited-bandwidth input channel information, such that mix coefficient values may be generated that accentuate the substantially audible frequencies that are perceivable by human listeners. Further, the downmixer may be capable of adjusting mix coefficient values, responsive to a ratio of energy at some combination of a plurality of the input channels (i.e., a ratio of front channel energy to rear channel energy, etc...). The mix coefficients may be adjusted, for example, to emphasize detected beginnings of sound events, such as notes from an instrument, or syllables in speech, when downmixing the input signal. In addition, or in the alternative, the mix coefficient values may be adjusted to provide a more accurate rendition of reverberation of the input signal at the output signal. In addition, the downmixer may be capable of preserving intended direction of a input signal when the downmixed signal is later upmixed, for example, at a decoder. The decoder may be capable of determining that surround channel information that has been downmixed in accordance to at least some of the teachings described herein is surround channel information that may be upmixed as surround channel information.

[148] The downmixers 100 and 900 are typically implemented as programming executed on one or more microprocessors for carrying out the functionalities described herein. However, it will be apparent that the downmixers may be implemented using any combination of hardware devices and/or programming executed on one or more microprocessors to carry out the functionalities described herein.

[149] Similarly, the controllers 106 and 940 may be comprised of any combination of hardware devices designed for specific functionalities (including, for example, applications specific integrated circuits capable of providing functionalities such as filtering, mixing, and alike). The controllers 106 and 940 may be comprised of a microprocessor(s) executing programmed code to achieve the functionalities described with respect to the controllers 106 and 940.

[150] The storage device 120 and the storage device 942 may comprise one or more fixed or removable storage devices including, but not limited to, solid state media, magnetic

and optical media. The solid state media may include, but is not limited to, integrated circuits such as ROMs, PROMs, EPROMs, EEPROMs, and any type of RAM, as well as removable memory storage devices such as a flash media card, and any derivative memory systems of these devices. The magnetic media may include, but is not limited to, magnetic tape,

5 magnetic disks such as floppy diskettes and hard disk drives. The optical media may include, but is not limited to, optical disks such as a Compact Disc and a Digital Video Disc.

Typically, the storage devices 120 and 942 include working memory (RAM) portion, and a program memory portion for storing programmed code for any microprocessors implementing the functionalities described herein. Further, the storage devices 120 and 942
10 may further include a sufficient storage medium for storing, for example, mix coefficient tables for downmixing the input signal to the output signal, described above.

[151] Although the downmixers 100 and 900, and specifically the controllers 106 and 940, have been described as averaging input and output signal energies over a particular time period, for example, the first time period, it will be apparent that the averaging may be
15 accomplished over other time periods. Further, it will be apparent that at least some of the advantages discussed above may be achieved where the input and/or output signal energy is not averaged.

[152] Further, although it has been described that the one or more mix coefficients are generated in a test mixer, it will be apparent that a test mixer need not be provided, where
20 the mix coefficients may be generated and/or adjusted during operation of the full-bandwidth downmixers 102 and 901 while the respective full-bandwidth downmixer is downmixing the input signal to the output signal, while achieving at least some of the advantages discussed above.

[153] While various embodiments of the invention have been described, it will be
25 apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the invention. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.

CLAIMS

What is claimed is:

1. A method of generating mix coefficients for downmixing a multi-channel input signal
5 having a plurality of input channels, to an output signal having a plurality of output channels, comprising:
determining an input energy at a plurality of input channels of the input signal; and
generating at least one mix coefficient responsive to the input energy where the input
signal energy, and the apparent direction of the input signal are substantially preserved in the
10 output signal.
2. The method of Claim 1, further comprising:
determining an output energy for at least one of the output channels;
where the generating at least one mix coefficient includes generating at least one mix
15 coefficient responsive to the determining the input energy and the determining output energy
where the input signal energy, and the apparent direction of the input signal are substantially
preserved in the output signal.
3. The method of Claim 2, further comprising:
20 generating a feedback constant responsive to the input and output energy;
where the generating at least one mix coefficient includes generating at least one mix
coefficient responsive to the feedback constant.
4. The method of Claim 3, where the generating the feedback constant includes
25 generating the feedback constant responsive to a ratio of the output energy to the input
energy.
5. The method of Claim 3, where the generating the feedback constant includes
averaging the feedback constant.

30

6. The method of Claim 3, where:

determining the input energy includes averaging the input energy over a first time period, and determining the output energy includes averaging the output energy over the first time period; and

5 generating the feedback constant includes averaging the feedback constant over a second time period.

7. The method of Claim 6, where the second time period includes a plurality of iterations of the first time period.

10

8. The method of Claim 2, further comprising:

determining at least one of a left input channel, center input channel, and right input channel of the input signal; and

15 determining a left output channel and a right output channel of the output signal, the left output channel energy determined responsive to at least one of the left and center input channel, and the right output channel energy determined responsive to at least one of the right and center input channel;

where

20 determining the input energy includes determining the input energy responsive to at least one of the left, center and right input channels, and

determining the output energy includes determining an output energy responsive to at least one of for at least one of the left output channel and a right output channel.

25 9. The method of Claim 8, further comprising:

generating at least one feedback constant responsive to at least one of the input and output energy;

where generating at least one mix coefficient includes generating at least one mix coefficient responsive to the at least one feedback constant.

30

10. The method of Claim 9, where:

determining the input energy includes determining at least one of a left channel total input energy responsive to at least one of the left and center input channels, and a right channel total input energy responsive to at least one of the right and center input channels;

determining the output energy includes determining at least one of a left output channel energy responsive to at least one of the left and center input channels, and a right output channel energy responsive to at least one of the right and center input channels; and

generating at least one feedback constant includes generating a left channel feedback constant responsive to at least one of the left channel total input energy and the left channel output energy, and generating a right channel feedback constant responsive to at least one of the right channel total input energy and the right channel output energy;

where generating at least one mix coefficient includes generating at least one mix coefficient responsive to at least one of the left and right channel feedback constants.

11. The method of Claim 10, where the generating at least one mix coefficient includes:

generating a left channel mix coefficient responsive to at least one of the left channel feedback constant and the right channel feedback constant; and

generating a right channel mix coefficient responsive to at least one of the left channel feedback constant and the right channel feedback constant.

12. The method of Claim 10, where:

generating a left channel feedback constant includes generating the left channel feedback constant responsive to a ratio of the left channel output energy to the left channel total input energy; and

generating a right channel feedback constant includes generating the right channel feedback constant responsive to a ratio of the right channel output energy and the right channel total input energy.

13. The method of Claim 10, where:

determining the left and right channel total input energy and determining the left and right channel output energy includes averaging the left and right channel total input energy and the left and right channel output energy over a first time period; and

generating the at least one feedback constant includes averaging the at least one feedback constant over a second time period.

14. The method of Claim 13, where the generating at least one mix coefficient includes
5 averaging at least one mix coefficient over the second time period.

15. The method of Claim 13, where the second time period includes a plurality of iterations of the first time period.

10 16. The method of Claim 10, where:

determining the input energy includes determining a low frequency input channel of the input signal; and

determining the left and right channel total input energy includes determining at least one of the left and right channel total input energy responsive to the low frequency input
15 channel.

17. The method of Claim 10, where the input energy is a front channel input energy, the output energy is a front channel output energy, and the at least one generated mix coefficient is at least one front channel mix coefficient, and further comprising:

20 determining at least one of a left surround input channel and a right surround input channel;

determining at least one of a left surround output channel and a right surround output channel, the left surround output channel determined responsive to at least one of the left surround input channel and the right surround input channel, and the right surround output
25 channel determined responsive to at least one of the left surround input channel and the right surround input channel;

where

determining the input energy includes determining a surround input channel energy responsive to at least one of the left and right surround input channels,

30 determining the output energy includes determining a surround output channel energy responsive to at least one of the left surround output channel and a right surround output channel, and

determining at least one mix coefficient includes determining at least one surround mix coefficient, such that the apparent direction of the input signal is substantially preserved in the output signal, the front channel input energy is substantially equal to the front output energy, and the surround input energy is substantially equal to the surround output energy.

18. The method of Claim 17, further comprising:

phase shifting at least one of the left and right surround output channels by 90 degrees to generate a respective left surround phase-shifted output channel and right surround phase shifted output channel.

19. The method of Claim 18, further comprising:

mixing at least one of

the phase-shifted left surround output channel with the left output channel, and

the phase-shifted right surround channel with the right output channel; and

forming at least one of

a left output channel of the output signal responsive to mixing phase-shifted left surround output channel with the left output channel, and

a right output channel of the output signal responsive to the mixing of the phase-shifted right surround channel with the right output channel.

20. The method of Claim 8, where the determining the left, center and right input channels includes filtering the left, center and right input channels, and further including:

determining limited-bandwidth left input channel energy responsive to at least one of the limited-bandwidth left and center input channels;

determining limited-bandwidth right input channel energy responsive at least one of the limited-bandwidth right and center channels;

determining limited-bandwidth left output channel energy responsive to at least one of the limited-bandwidth left and center input channels;

determining limited-bandwidth right output channel energy responsive to at least one of the limited-bandwidth right and center input channels;

where generating at least one mix coefficient includes generating at least one mix coefficient responsive to at least one of the limited-bandwidth left input, right input, left output and right output channel energy.

5 21. The method of Claim 20, where the filtering the left, center and right input channels includes band-pass filtering the left, center and right input channels.

22. The method of Claim 21, where the band-pass filtering includes band-pass filtering in the 700 – 4000 Hz frequency band.

10 23. The method of Claim 2, further comprising:
determining at least one of a left surround input channel of the input signal, and a right surround input channel of the input signal; and
determining at least one of a left surround output channel and a right surround output
15 channel of the output signal, the left surround output channel determined responsive to at least one of the left and right surround input channels, the right surround output channel determined responsive to at least one of the left and right surround input channels;

where

determining an input energy includes determining the input energy responsive
20 to at least one of the left and right surround input channels, and

determining an output energy includes determining the output energy responsive to at least one of the left and right surround output channels.

24. The method of claim 23, further comprising:
25 generating a feedback constant responsive to at least one of the input and output surround channel energy;

where the generating at least one mix coefficient includes generating at least one mix coefficient responsive to the feedback constant.

30 25. The method of Claim 24, further comprising:

determining a left surround output channel real portion and a left surround output channel imaginary portion of the left surround output channel; and

determining a right surround output channel real portion and a right surround output channel imaginary portion of the right surround output channel;

5 where

 determining the output energy includes determining the output energy responsive to at least one of the left surround real portion, left surround imaginary portion, right surround real portion, and right surround imaginary portion of the output signal, and

 generating at least one mix coefficient includes generating at least one of a
10 surround-imaginary mix coefficient and a surround-real mix coefficient responsive to the feedback constant.

26. The method of Claim 25, where generating at least one of the surround-imaginary and surround-real mix coefficients includes generating at least one of the surround-imaginary and
15 surround-real mix coefficients responsive to a value of the other of the surround-imaginary and surround-real mix coefficients.

27. The method of Claim 26, where the generating at least one of the surround-imaginary and surround real mix coefficients includes:

20 setting a value of the surround-real mix coefficient to zero when a value of the surround-imaginary mix coefficient is less than one.

28. The method of Claim 26, where the generating at least one of the surround-imaginary and surround real mix coefficients includes:

25 setting a value of the surround-imaginary mix coefficient to one when a value of the surround-real mix coefficient is greater than zero.

29. The method of Claim 25, further comprising:

30 determining at least one of a front left input channel, a front center input channel and a front right input channel;

 determining a front input channel energy responsive to at least one of the front left, center and right input channels; and

determining a surround channel input energy responsive to at least one of the left surround and right surround input channels;

where the generating at least one of the surround-imaginary and surround-real mix coefficients includes generating at least one of the surround-imaginary and surround-real mix coefficients responsive to a front/surround energy ratio determined responsive to a ratio of the front input channel energy and the surround input channel energy.

30. The method of Claim 28, where generating at least one of the surround-imaginary and surround-real mix coefficients responsive to the front/surround energy ratio includes reducing at least one of a value of the surround-real mix coefficient and a value of the surround-imaginary mix coefficient when the front/surround ratio is greater than one.

31. The method of Claim 25, further comprising:
detecting a beginning of a sound event;
where the determining at least one of the surround-imaginary mix coefficient and surround-real mix coefficient includes determining at least one of the surround-imaginary mix coefficient and surround-real mix coefficient responsive to the detection.

32. The method of Claim 24, where the generating at least one feedback constant includes generating at least one feedback constant responsive to a ratio of the output channel energy to the input channel energy.

33. The method of Claim 32, further comprising:
filtering at least one of the input energy and the output energy;
where generating the feedback constant includes generating the feedback constant responsive to at least one of the filtered input and output energy.

34. The method of Claim 33, where:
determining the input channel energy and determining the output energy includes averaging the input energy and output energy over a first time period; and
generating the at least one feedback constant includes averaging the at least one feedback constant over a second time period.

35. The method of Claim 34, where the generating at least one mix coefficient includes averaging at least one mix coefficient over the second time period.

5 36. The method of Claim 34, where the second time period includes a plurality of iterations of the first time period.

37. The method of Claim 1, where generating at least one mix coefficient comprises retrieving at least one mix coefficient from a storage device responsive to the input energy.

10

38. The method of Claim 37, where:

determining at least one of a front left, front center and front right input channels of the input signal; and

15 retrieving at least one mix coefficient includes retrieving at least one mix coefficient responsive to a panning angle between at least one of a front left and front center input channel, and a front right and front center input channel.

39. The method of Claim 38, further comprising:

20 determining at least one of a front left channel input energy, a front center channel input energy and a front right channel input channel energy, the front left input channel energy determined responsive to the front left input channel, the front center input channel energy determined responsive to the front center input channel, and the front right input channel energy determined responsive to the front right input channel;

25 determining a panning angle between a front left and front center input channel includes determining the panning angle responsive to the front left and center input channel energy; and

determining a panning angle between a front right and front center input channel includes determining the panning angle responsive to the front right and center input channel energy.

30

40. The method of Claim 38, where the at least one generated mix coefficient is a front channel mix coefficient, and further comprising generating at least one surround channel coefficient responsive to the panning angle.

5 41. The method of Claim 1, further comprising generating the output signal responsive to at least one generated mix coefficient.

42. The method of Claim 1, further comprising downmixing the plurality of input channels of the input signal to the number of channels of the output signal responsive to the
10 at least one generated mix coefficient.

43. The method of Claim 42, where the generating the at least one mix coefficient includes generating at least one mix coefficient in a test downmixer environment, and the downmixing the plurality of input signals includes downmixing the plurality of input
15 channels of the input signal to the number of output channels of the output signal in a non-test downmixer environment.

44. The method of Claim 1, where the number of input channels of the input signal is one of 3, 5, 5.1 and 7.

20 45. The method of Claim 44, where the number of output channels of the output signal is 2.

46. The method of Claim 1, where the generating at least one mix coefficient includes
25 generating at least one of a left front channel mix coefficient, a right front channel mix coefficient, a left surround channel mix coefficient, and a right surround channel mix coefficient.

47. The method of Claim 1, where the generating at least one mix coefficient includes
30 generating at least one mix coefficient by adjusting a mix coefficient determined in accordance with the Sine/Cosine pan law .

48. The method of Claim 1, where the generating at least one mix coefficient includes providing at least one of an upper value limit and a lower value limit for at least one of the generated mix coefficients.

5 49. The method of Claim 1, where the generating at least one mix coefficient includes generating at least one mix coefficient in accordance with feedback techniques.

50. The method of Claim 1, where the generating at least one mix coefficient includes generating at least one mix coefficient in accordance with feedforward techniques.

10

51. The method of Claim 1, where the plurality of input channels is equal in number to the plurality of output channels.

52. The method of Claim 1, where the plurality of input channels is greater in number
15 than the plurality of output channels.

53. A downmixer for downmixing a multichannel input signal including a plurality of input channels to an output signal including a plurality output channels, comprising:
an input signal source for receiving at least one of the input channels of the input
20 signal;

a controller coupled with the input signal source, capable of

determining an input energy at a plurality of input channels of the input signal,

and

generating at least one mix coefficient responsive to the input energy where
25 the input signal energy, and the apparent direction of the input signal are substantially preserved in the output signal.

54. The downmixer of Claim 53, where the controller is further capable of:

determining an output energy for at least one of the output channels;

30 where the generating at least one mix coefficient includes generating at least one mix coefficient responsive to the input energy and the output energy, such that the input signal

energy, and the apparent direction of the input signal are substantially preserved in the output signal.

55. The downmixer of Claim 54, where the controller is further capable of generating at least one feedback constant responsive to at least one of the input and output channel energy, where the controller is capable of generating at least one of the mix coefficients responsive to the at least one feedback constant.

56. The downmixer of Claim 55, where the controller being capable of determining the input and output energy includes the controller being capable of determining the input and output energy over a first time period.

57. The downmixer of Claim 56 where the controller being capable of determining the at least one feedback constant includes the controller being capable of averaging the at least one feedback constant over a second time period.

58. The downmixer of Claim 57, where the controller being capable of generating at least one mix coefficient includes the controller being capable of averaging at least one of the generated mix coefficients over the second time period.

59. The downmixer of Claim 57, where the second time constant includes multiple iterations of the first time constant.

60. The downmixer of Claim 54, where the controller determining at least one of the input and output energy includes the controller being capable of filtering at least one of the input and the output energy, where the controller being capable of generating the at least one mix coefficients includes generating at least one of the mix coefficients responsive to the at least one filtered input and output energy.

61. The downmixer of Claim 53, where the controller being capable of generating at least one mix coefficient includes the controller being capable of generating at least one of a left

front channel mix coefficient, a right front channel mix coefficient, a left surround channel mix coefficient, and a right surround channel mix coefficient.

62. The downmixer of Claim 53, where the controller is further capable of downmixing the plurality of input channels of the input signal to the number of channels of the output signal responsive to the at least one generated mix coefficient.

63. The downmixer of Claim 53, where the number of input channels of the input signal is one of 3, 5, 5.1 and 7.

64. The downmixer of Claim 63, where the number of output channels of the output signal is 2.

65. The downmixer of Claim 53, where the controller being capable of generating at least one mix coefficient includes the controller being capable of generating at least one mix coefficient by adjusting a mix coefficient determined in accordance with a Sine/Cosine pan law.

66. The downmixer of Claim 53, where the controller being capable of generating at least one mix coefficient includes the controller being capable of limiting an upper value of and a lower value of at least one of the generated mix coefficients.

67. The downmixer of Claim 53, further comprising:
a storage device coupled with the controller;

where the controller being capable of generating at least one mix coefficient includes the controller being capable of retrieving at least one mix coefficient from the storage device responsive to the input channel energy.

68. The downmixer of Claim 67, further comprising:
the controller being capable of determining at least one of a front left, front center and front right input channels of the input signal;

the controller being capable of retrieving the at least one mix coefficient includes retrieving at least one mix coefficient responsive to a panning angle between at least one of a front left and front center input channel, and a front right and front center input channel.

5 69. The downmixer of Claim 53, where the plurality of input channels is equal in number to the plurality of output channels.

70. The downmixer of Claim 53, where the plurality of input channels is greater in number than the plurality of output channels.

10

71. A downmixer for generating mix coefficients for downmixing a multichannel input signal having a plurality of input channels, to an output signal having a plurality of output channels, comprising:

15 means for determining an input energy at a plurality of input channels of the input signal; and

means for generating at least one mix coefficient responsive to the input energy where the input signal energy, and the apparent direction of the input signal are substantially preserved in the output signal.

20 72. The downmixer of Claim 71, further comprising:

means for determining an output energy for at least one of the output channels;

where the means for generating at least one mix coefficient generates at least one mix coefficient responsive to the input energy and the energy, where the input signal energy, and the apparent direction of the input signal are substantially preserved in the output signal.

25

73. The downmixer of Claim 72, further comprising:

means for generating a feedback constant responsive to the input and output energy;

where the means for generating at least one mix coefficient generates at least one mix coefficient responsive to the feedback constant.

30

74. A storage media for use on a processor of a downmixer, the downmixer for generating mix coefficients for downmixing a multichannel input signal having a plurality of input channels, to an output signal having a plurality of output channels, comprising:

a first memory portion programmed for determining an input energy at a plurality of
5 input channels of the input signal; and

a second memory portion programmed for generating at least one mix coefficient responsive to the input energy, where the input signal energy, and the apparent direction of the input signal, are substantially preserved in the output signal.

10 75. The storage media of Claim 74, further comprising:

a third memory portion programmed for determining an output energy for at least one of the output channels;

where the second memory portion being programmed for generating at least one mix coefficient includes generating at least one mix coefficient responsive to the input energy and
15 the energy, such that the input signal energy, and the apparent direction of the input signal are substantially preserved in the output signal.

76. The storage media of Claim 75, further comprising:

a fourth memory portion programmed for generating a feedback constant responsive
20 to the input and output energy;

where the second memory portion being programmed for generating at least one mix coefficient includes generating at least one mix coefficient responsive to the feedback constant.

25 77. A method of generating mix coefficients for downmixing a multi-channel input signal having a plurality of input channels, to an output signal having a plurality of output channels, comprising:

determining an input energy at a plurality of input channels of the input signal; and
generating at least one mix coefficient responsive to the input energy.

30 78. The method of Claim 77, further including detecting a beginning of a sound event in at least one of the input channels, where generating at least one mix coefficient includes

generating at least one mix coefficient responsive to the first input energy and the detected beginning of the sound event.

5 79. The method of Claim 78, where the determining an input energy includes:
determining a first input energy for at least one of the input channels; and
determining a second input energy for at least another of the input channels;
where the generating at least one mix coefficient includes generating at least one mix
coefficient responsive to the first input energy, second input energy, and the detected
beginning of the sound event.

10 80. The method of Claim 79, further comprising:
determining an energy ratio of the first and second input energy;
where the generating at least one mix coefficient includes generating at least one mix
coefficient responsive to the energy ratio and the detected beginning of the sound event.

15 81. The method of Claim 77, where the generating at least one mix coefficient includes
generating at least one mix coefficient responsive to the input energy where the apparent
direction of the input signal is substantially preserved at the output signal.

20 82. The method of Claim 77, where the plurality of input channels is equal in number to
the plurality of output channels.

83. The method of Claim 77, where the plurality of input channels is greater in number
than the plurality of output channels.

25 84. The method of Claim 77, where the generating at least one mix coefficient includes
increasing a value of at least one mix coefficient.

30 85. A downmixer for downmixing a multichannel input signal including a plurality of
input channels to an output signal including a plurality of output channels, comprising:
an input signal source for receiving at least one of the input channels of the input
signal;

a controller coupled with the input signal source, capable of
determining an input energy at a plurality of input channels of the input signal,
detecting a beginning of a sound event in at least one of the input channels;
and
5 generating at least one mix coefficient responsive to the input energy and the
detected beginning of the sound event.

86. The downmixer of Claim 85, where the controller being capable of generating at least
one mix coefficient includes the controller being capable of increasing a value of at least one
10 mix coefficient.

87. The downmixer of Claim 85, where the controller being capable of determining an
input energy includes the controller being capable of:
determining a first input energy for at least one of the input channels; and
15 determining a second input energy for at least another of the input channels;
where the generating at least one mix coefficient includes generating at least one mix
coefficient responsive to the first input energy, second input energy, and the detected
beginning of the sound event.

88. The downmixer of Claim 87, further comprising the controller being capable of:
determining an energy ratio of the first and second input energy;
where the generating at least one mix coefficient includes generating at least one mix
coefficient responsive to the energy ratio and the detected beginning of the sound event.

89. The downmixer of Claim 85, where the the controller being capable of generating at
least one mix coefficient includes generating at least one mix coefficient responsive to the
input energy and the detected beginning of the sound event where the apparent direction of
the input signal is substantially preserved at the output signal.

90. The downmixer of Claim 85, where the plurality of input channels is equal in number
to the plurality of output channels.

91. The downmixer of Claim 85, where the plurality of input channels is greater in number than the plurality of output channels.

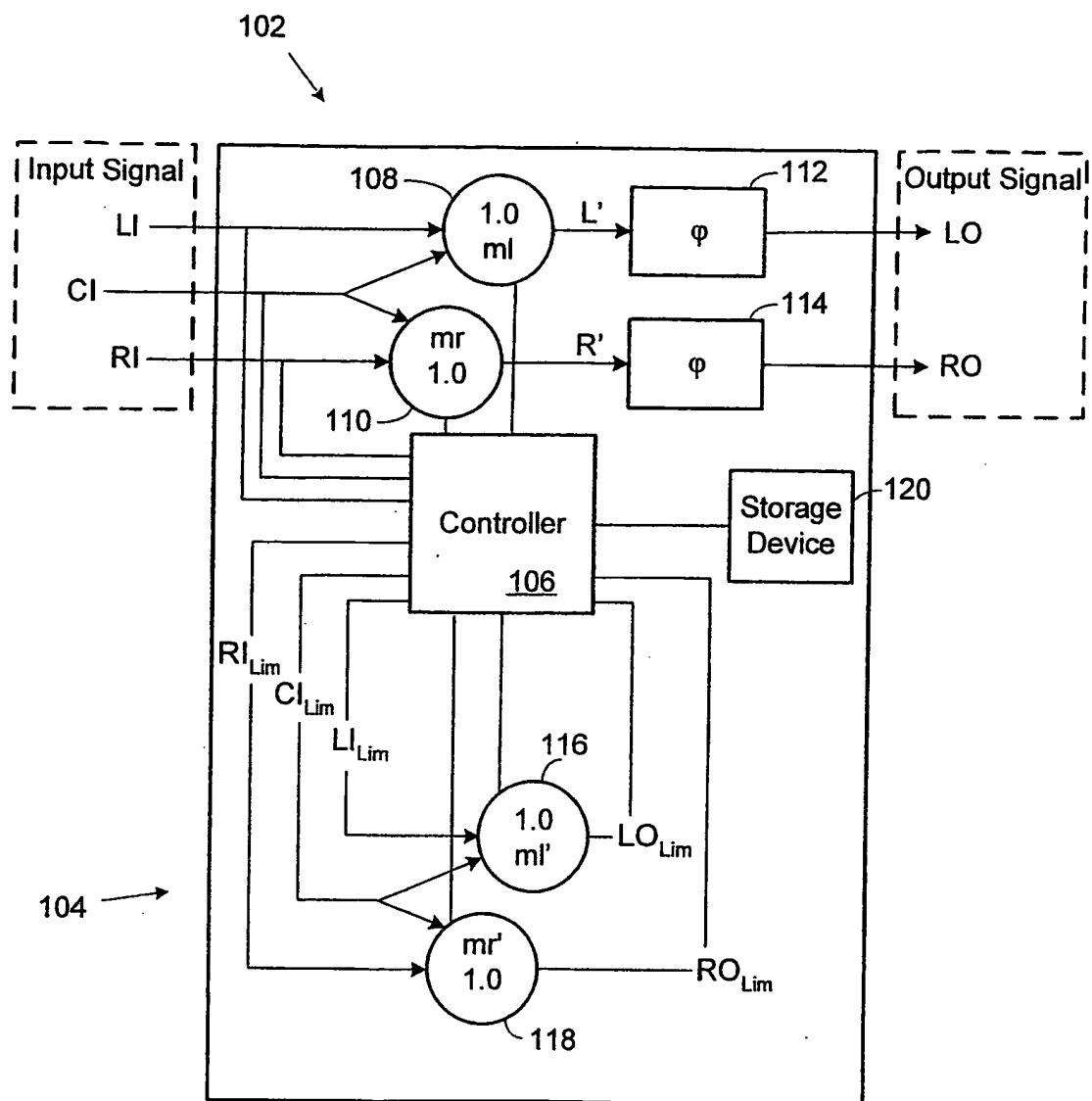


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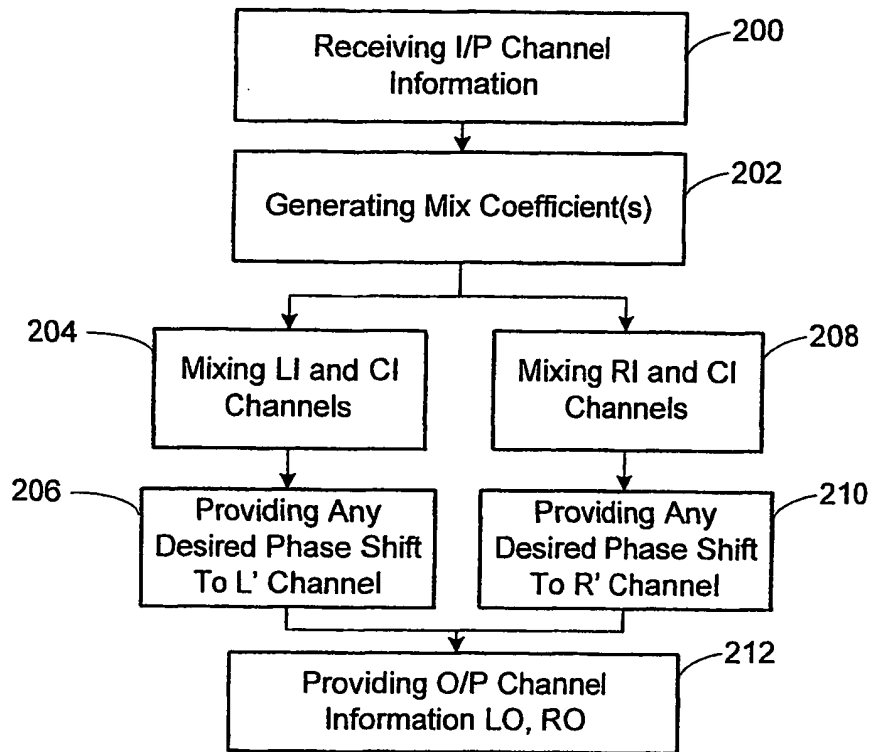


Figure 2

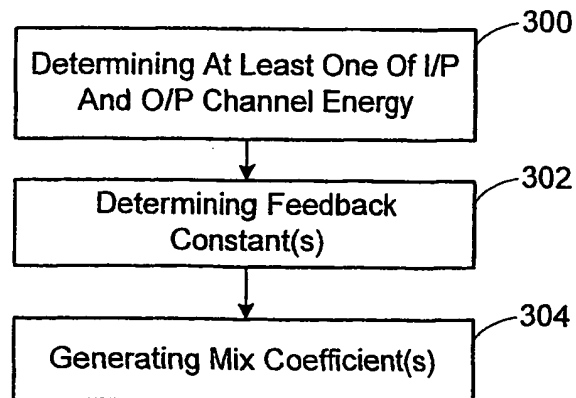


Figure 3

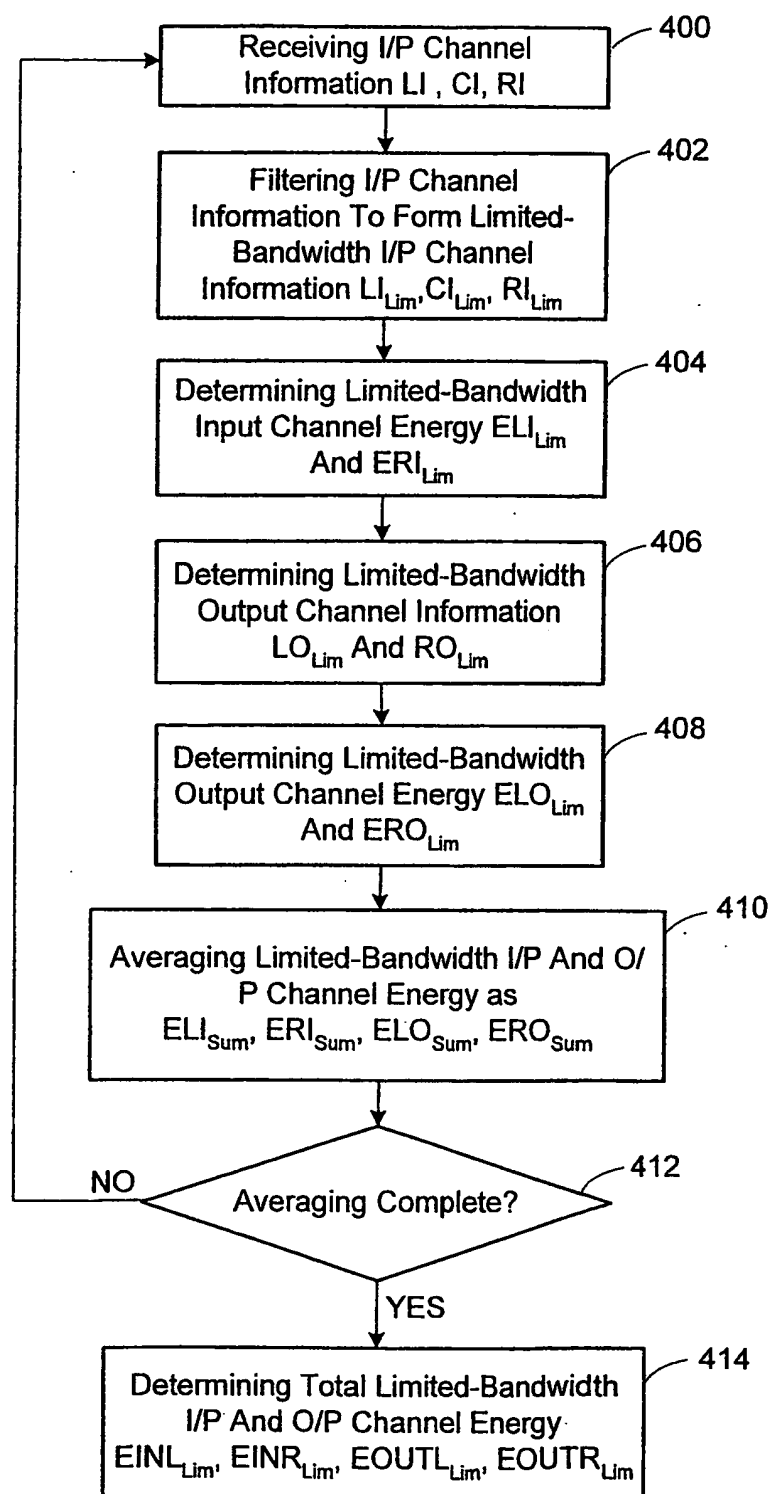


Figure 4

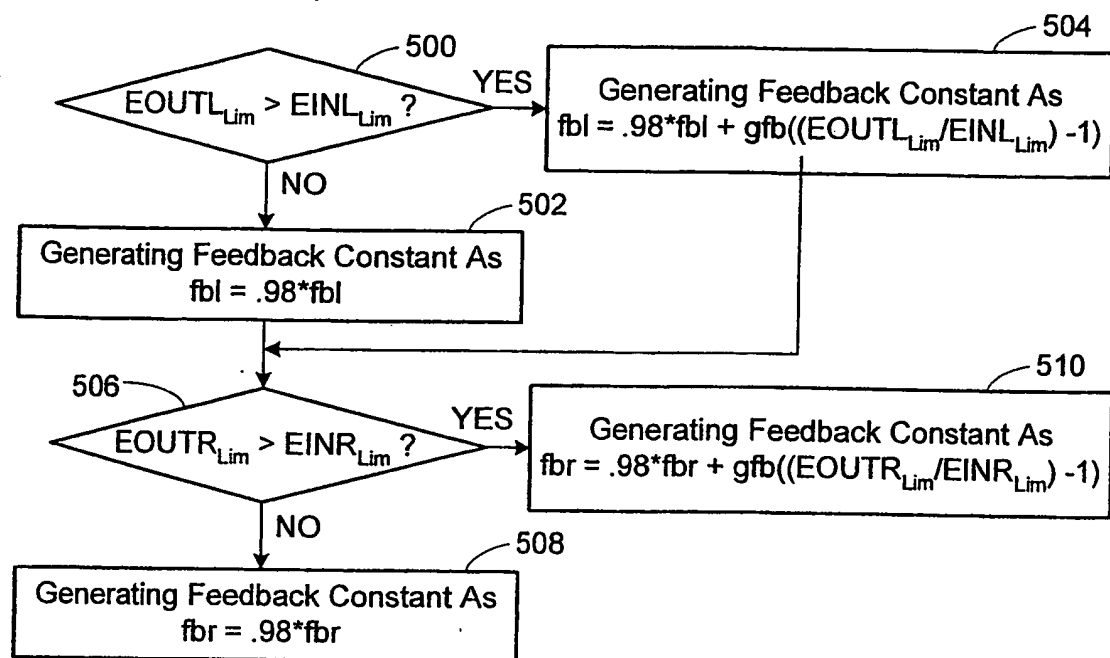


Figure 5

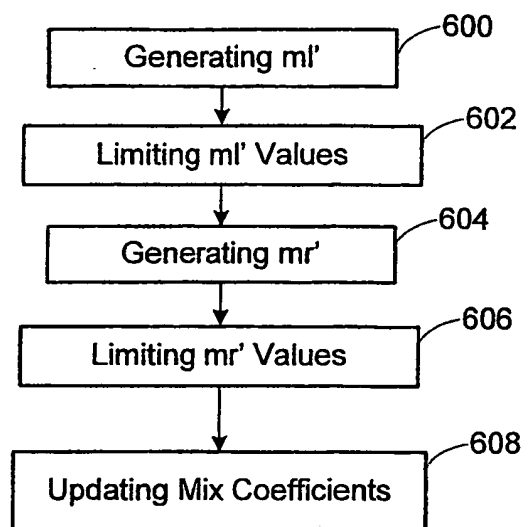


Figure 6

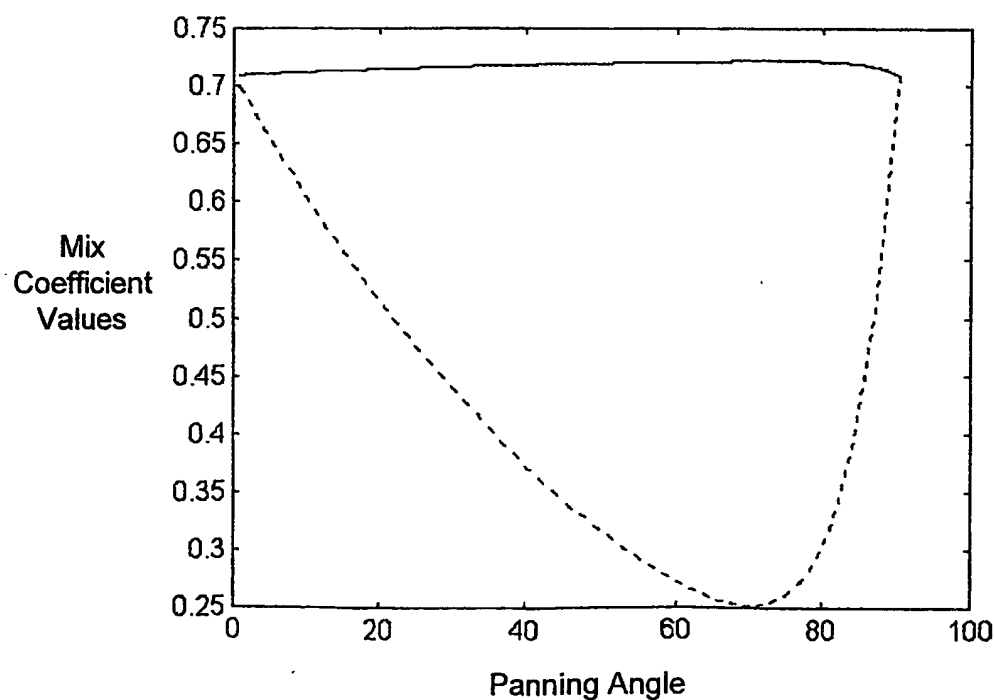


Figure 7

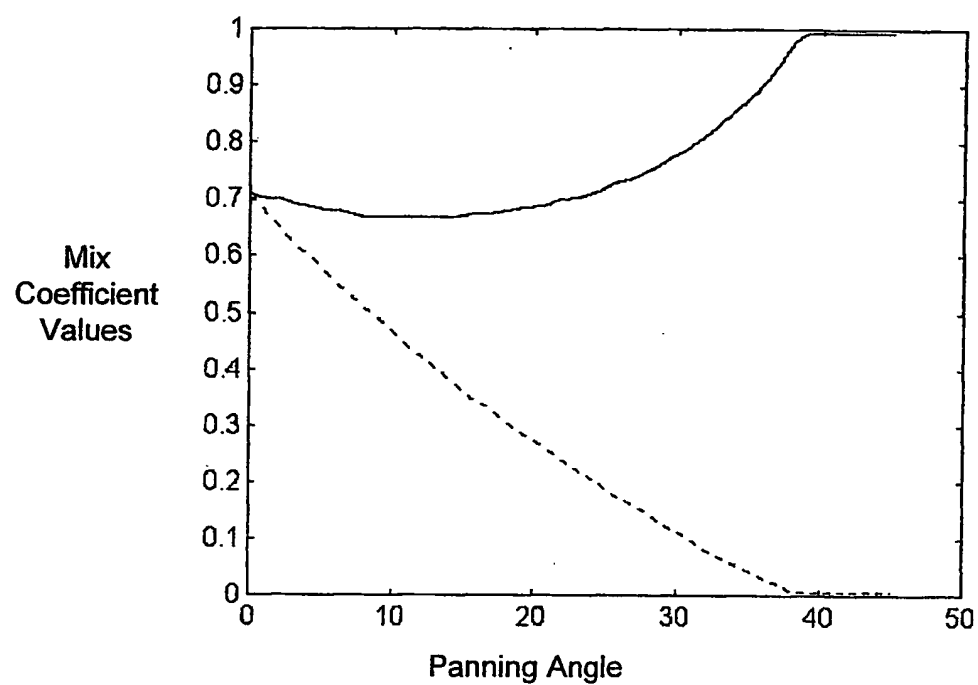


Figure 8

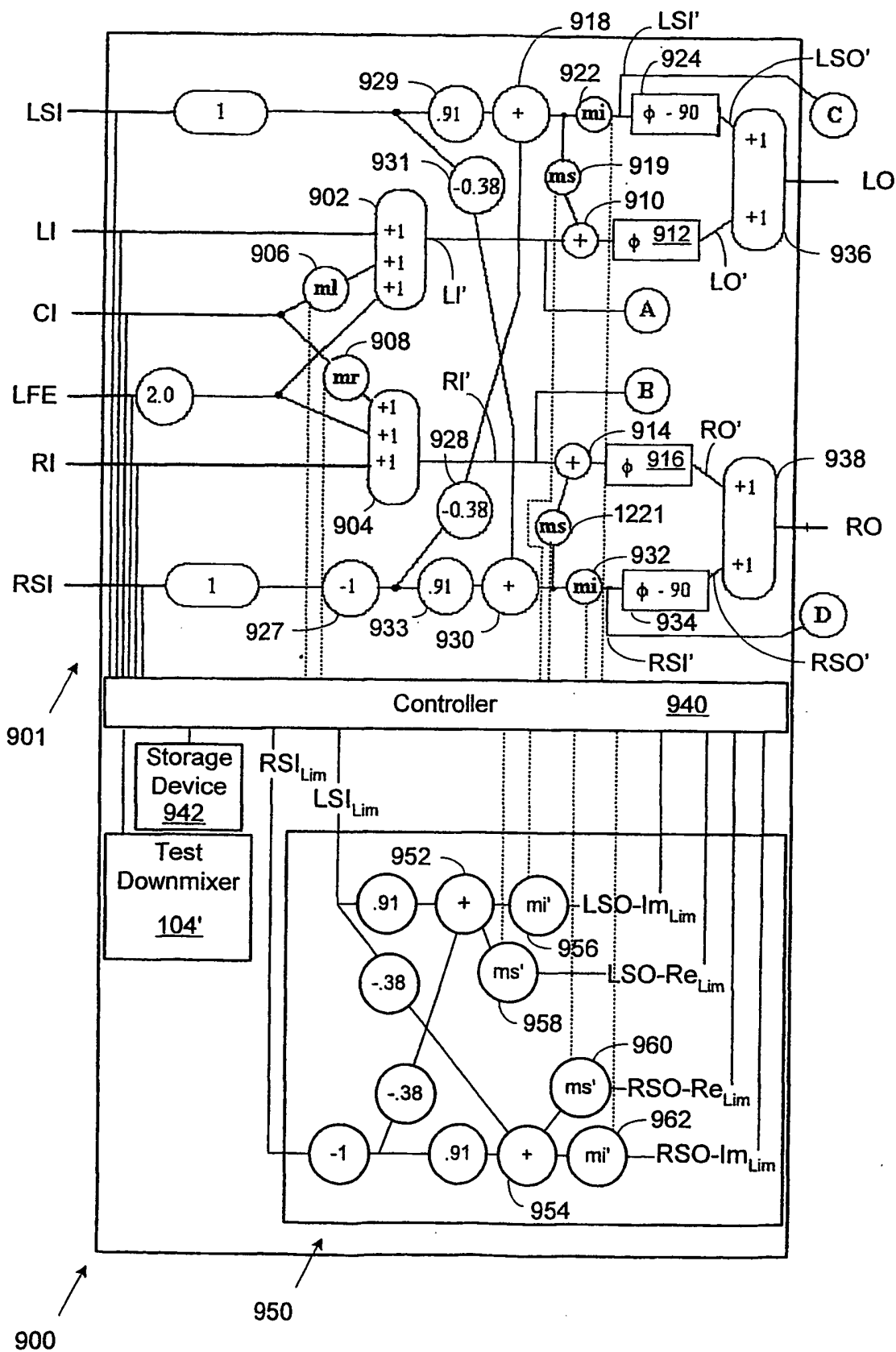


Figure 9

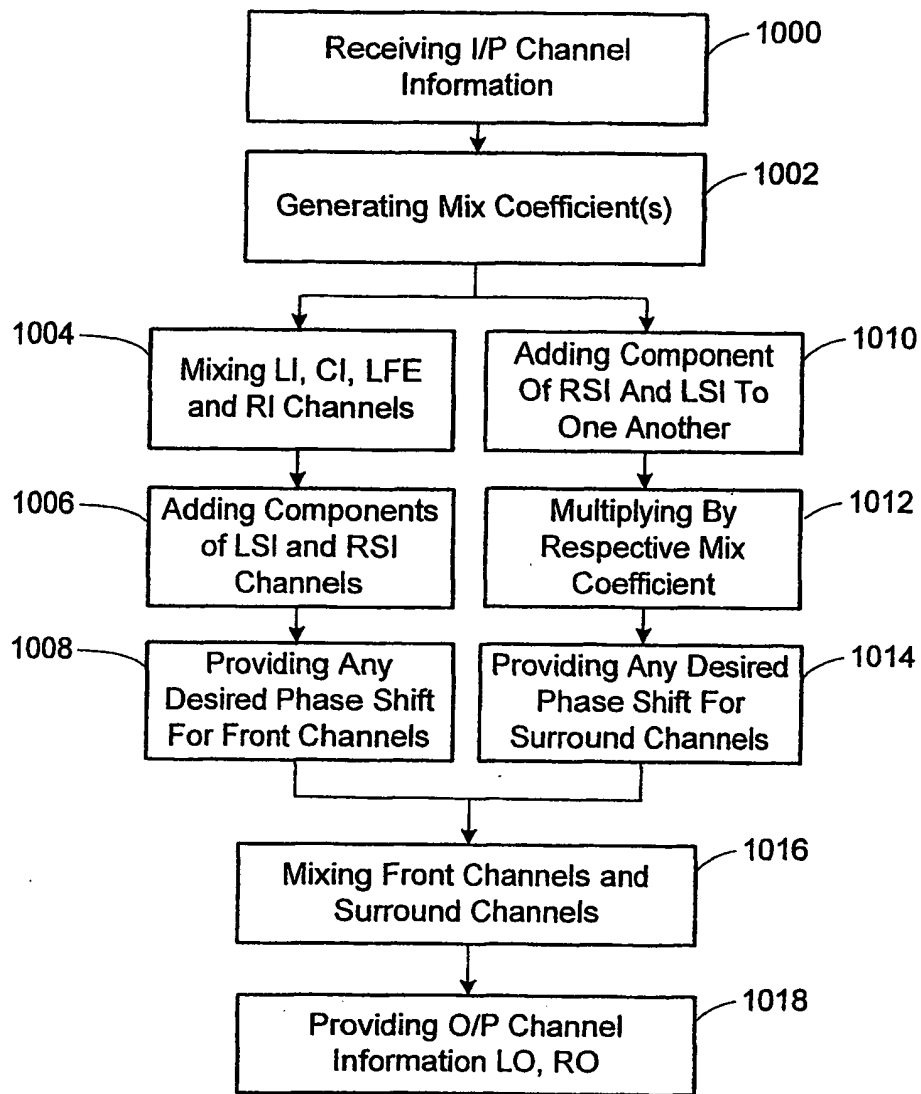


Figure 10

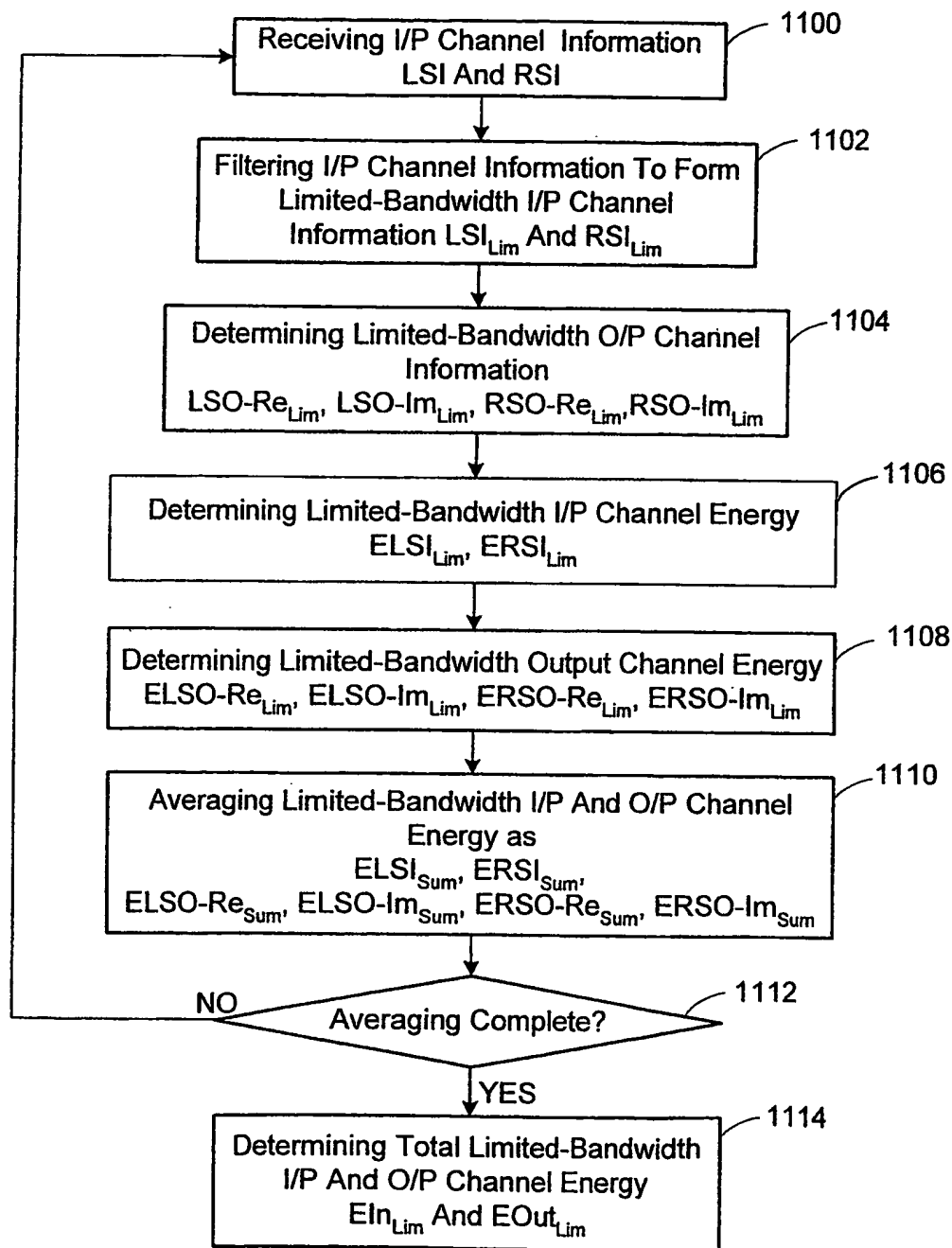


Figure 11

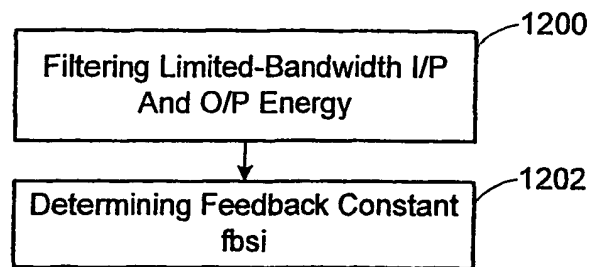


Figure 12

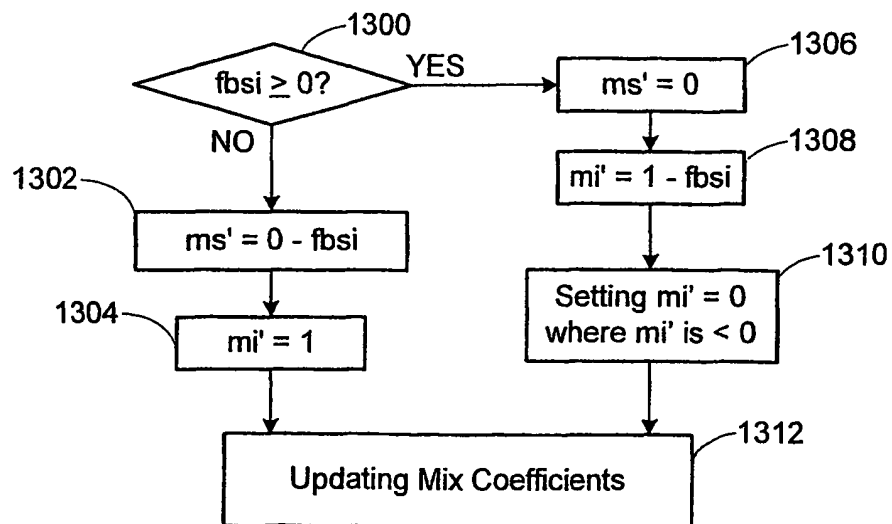


Figure 13

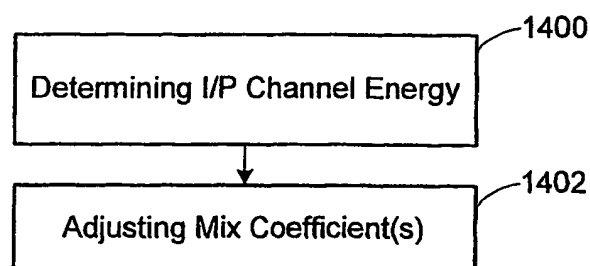


Figure 14

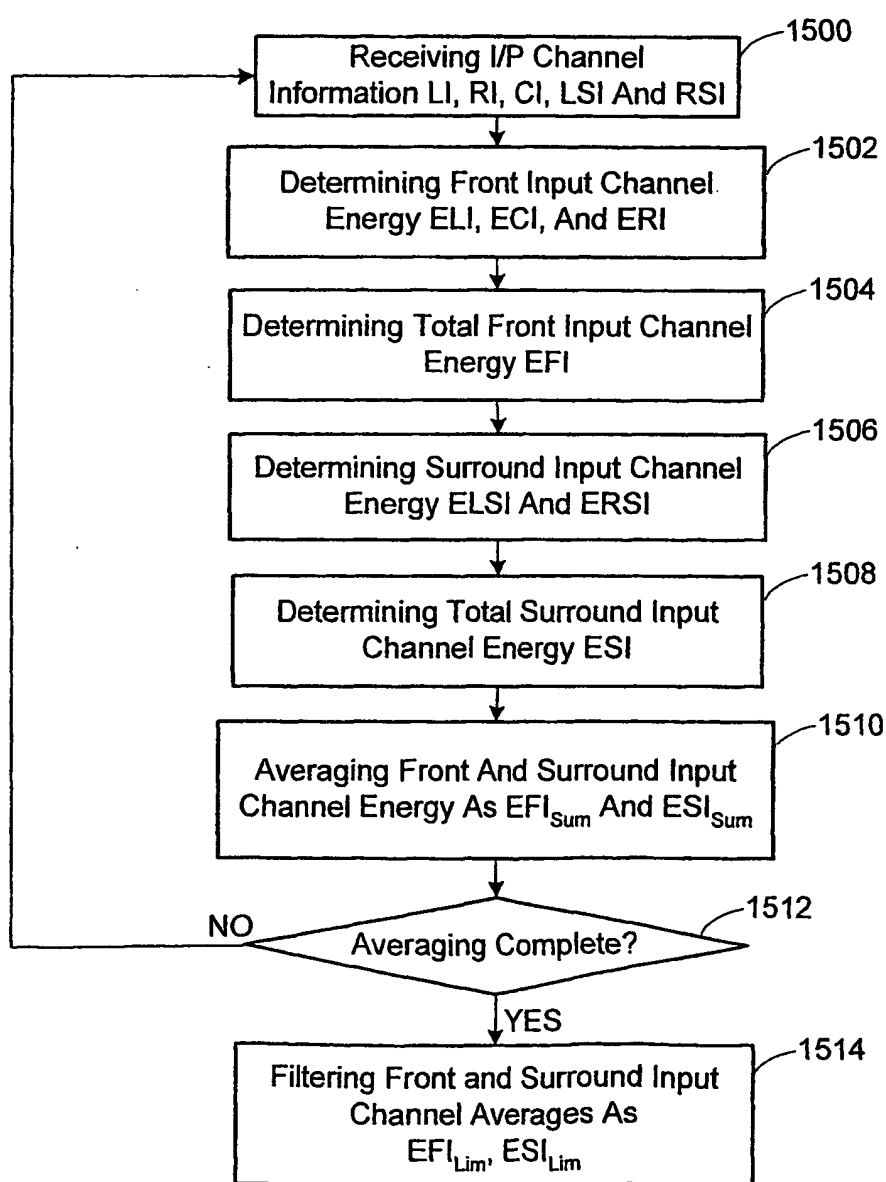


Figure 15

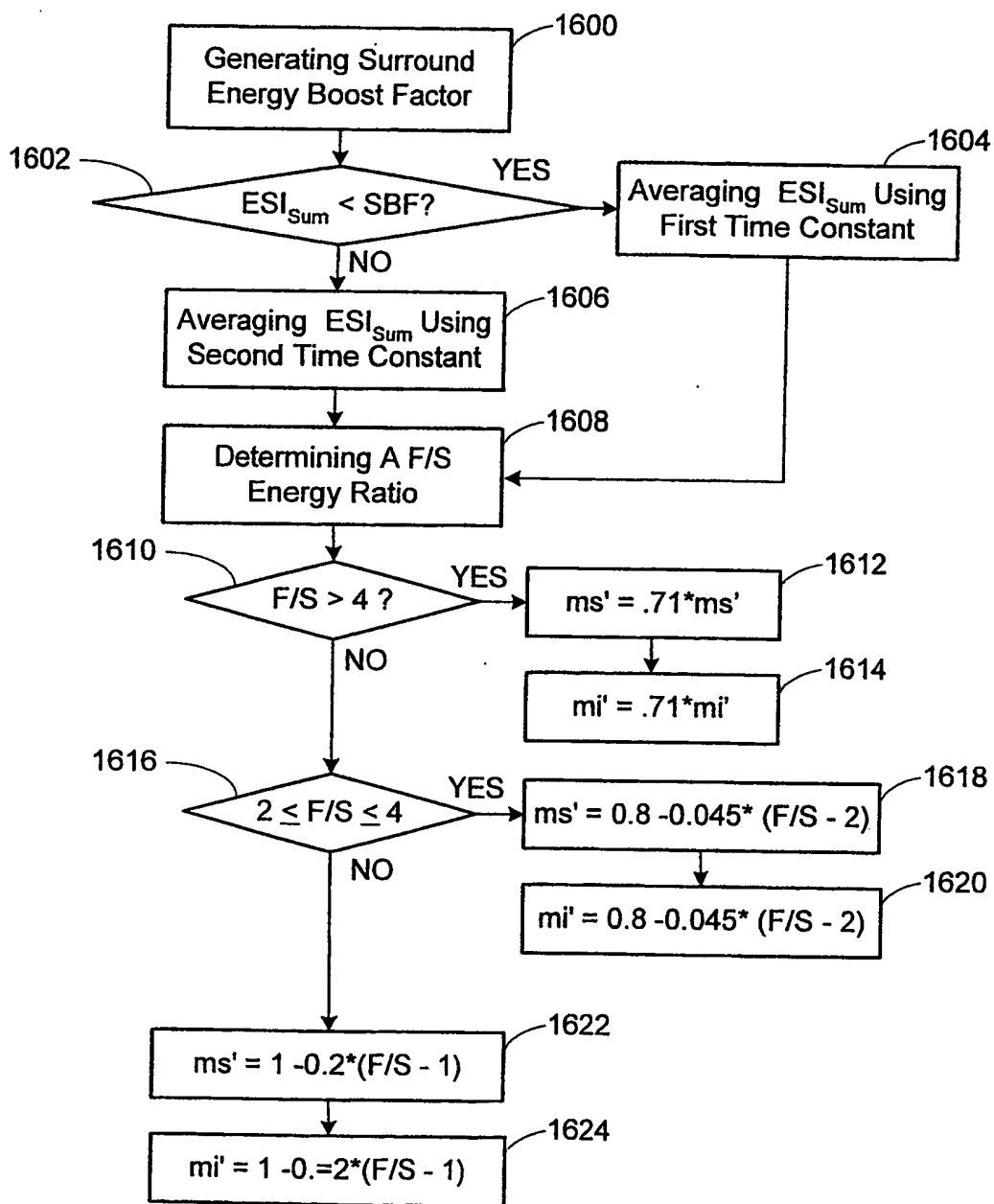


Figure 16

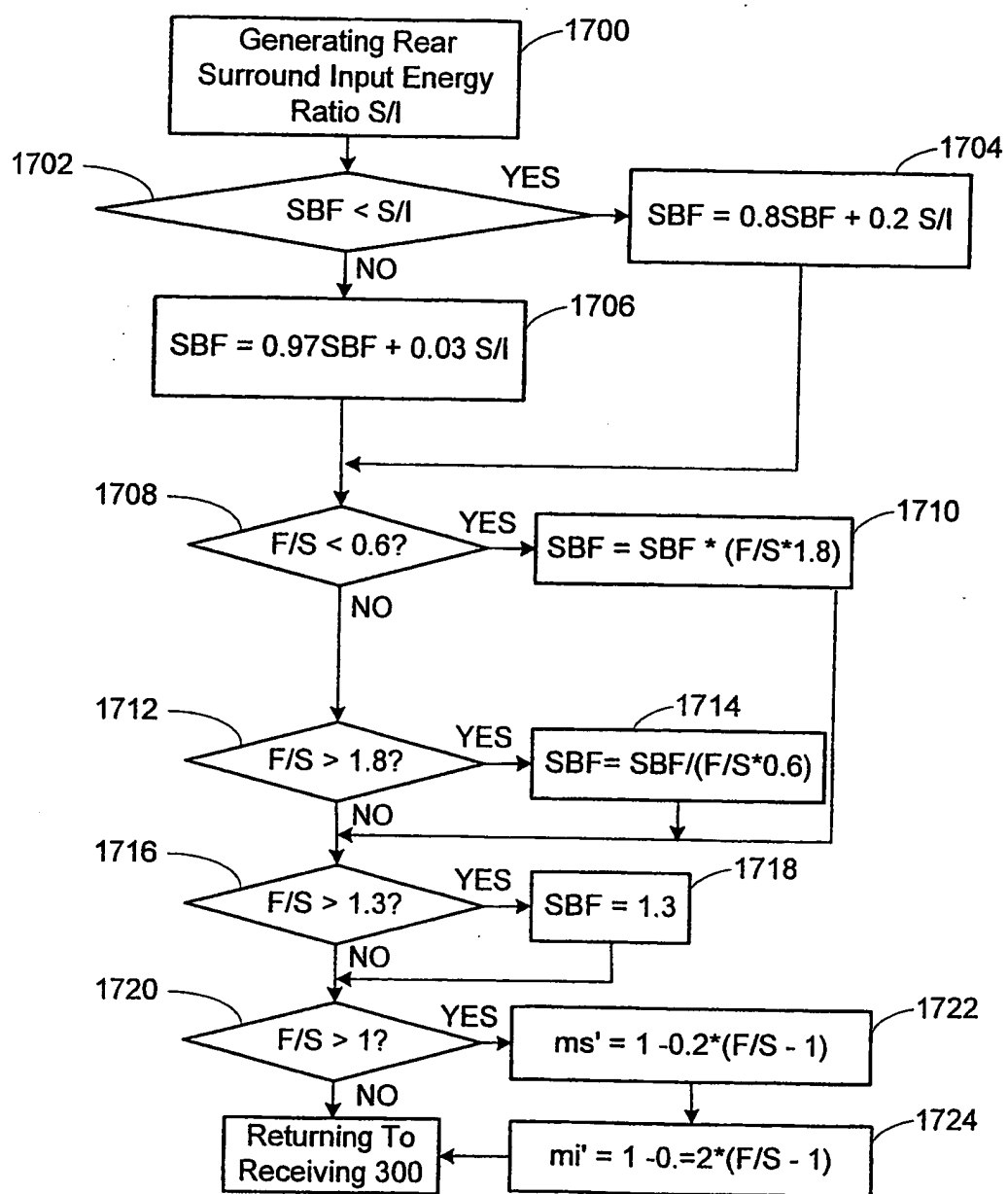


Figure 17

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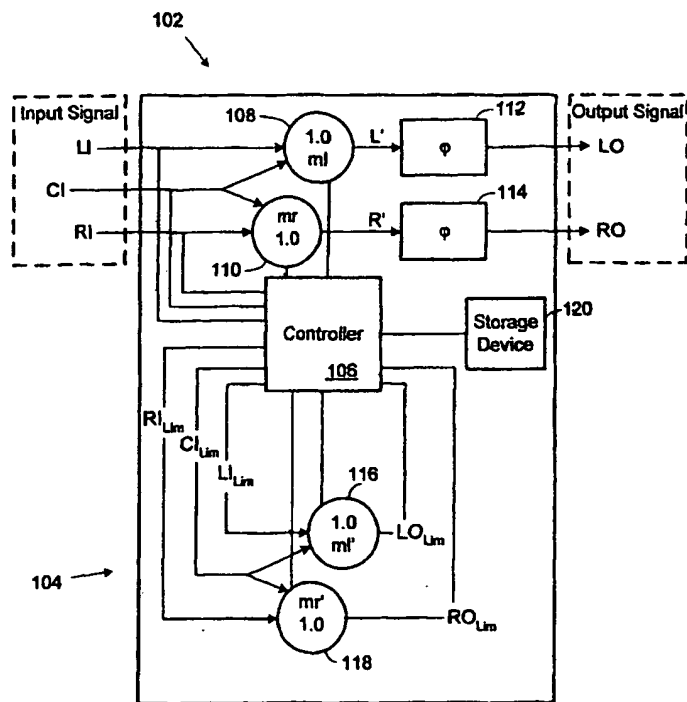
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[Continued on next page]

(54) Title: MULTI-CHANNEL DOWNMIXING DEVICE



(57) Abstract: A method and system (100) are provided for generating one or more mix coefficients (m_l , m_r) for downmixing a multichannel input signal having a plurality of input channels (L_I , C_I , R_I), to an output signal having a plurality of output channels (L_O , R_O). Mix coefficients may be generated responsive to a comparison of energy between the downmixed (output) signal and the input signal to the downmixer (100), such that energy and intended direction of the input signal are substantially preserved in the output signal. Further, the mix coefficient generation may preserve an intended direction of an input signal, for example, received at a surround input channel, in at least one output channel of the output signal. The mix coefficient values (m_l' , m_r') may be generated in a test downmixer (104) environment. Additionally, one or more mix coefficients may be generated by retrieving predetermined mix coefficient values.



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25 March 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/13693

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US CL : 381/119

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,141,645 A (CHI-MIN et al.) 31 October 2000 (31.10.2000), see entire document	1-91
A	US 5,870,480 A (GRIESINGER) 09 February 1999 (02.09.1999), see entire document	1-91
A	US 5,610,986 A (MILES) 11 March 1997 (11.03.1997), see entire document	1-91
A	US 5,594,800 A (GERZON) 14 January 1997 (14.01.1997), see entire document	1-91

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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INTERNATIONAL SEARCH REPORT

PCT/US03/13693

Continuation of B. FIELDS SEARCHED Item 3:

USPAT, US-PGPUB, EPO, JPO, DERWENT, IBM_TDB, IEEE Xplore, Google, CiteSeer.

search terms: downmixer, mixer, modulator, feedback, surround, coefficient, energy, bandwidth, Sine/Cosine pan law.